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WALDEMAR LINDGREN

1860–1939.

IN the fullness of years, honored throughout the world, and revered by all within the orbit of his personality, Waldemar Lindgren, geologist, teacher, wise and kindly gentleman, a founder and associate editor of this journal, died amid the peaceful surroundings of his home in Brighton, Massachusetts, on November 3, 1939. He had maintained his wonted activity until January, when first came evidence that human fibre cannot indefinitely withstand the amazing load he had ever carried. Finally, with sustained effort no longer possible, he took satisfaction in realizing that every important task was finished, and to the end retained his unselfishness of spirit and light-hearted acceptance of reality.

Lindgren's ancestry was auspicious. Through his father, Johan Magnus Lindgren, a man of influence and broad interests, a judge of the Province of Kalmar, descended the vigor, steadfastness and conservatism of a line of landholders in middle Sweden. From the side of his mother, Emma Bergman, daughter of a noted divine, came a heritage of imagination, leadership and responsibility from forebears long noteworthy in Swedish history, as typified by Count Carl Piper, Chancellor of the University of Upsala, Secretary of State under Charles XII, and Major General in the great campaign of the early eighteenth century against Poland and Russia. On February 14, 1860, in the historic city of Kalmar on the Baltic coast, Waldemar Lindgren was born into a home of culture, stability and righteousness.

Once the boy of ten had learned of mineralogy and geology his career was settled. Thenceforward, with sympathetic family encouragement, he studied, journeyed and observed, extending his

facility with languages, deepening his interest in human affairs, and at the age of twenty-three completing his broad and solid scientific foundation at the Freiberg *Bergakademie,* then the world's most illustrious school of mining and geology.

In 1883 he came to the United States, immediately securing geological work. Soon afterward he joined the United States Geological Survey, which was fast becoming the world's foremost organization for the practice and development of geological science. Until 1915 he remained a Survey member—thirty-one years crowded with accomplishment, marked by his own growth, and adding thereby to Survey strength and prestige.

After yearly lectures from 1908, he moved in 1912 to Massachusetts Institute of Technology to head its Department of Geology. His teaching was enriched by personal experience in many lands and by fruition of his scientific philosophy in the four editions of his *Mineral Deposits.* Like a magnet he drew able inquirers from afar, and generously opened his graduate seminar to students from Harvard. At the age of seventy-three he retired from active service as Professor Emeritus, though continuing blithely at writing and research.

In 1886 Lindgren married Ottolina Allstrin. Under her devoted hand, until her death in 1929, every circumstance was shaped to safeguard his well-being and efficiency, whether in remote mining camp or in the quiet charm of their established home where dwelt artistic appreciation, deeply satisfying intellectual interests and warm hospitality.

Tall, graceful, quick of step and alert in manner, skilled fencer, Lindgren brought to his incessant application a natural vitality which he conserved by wise but unostentatious ordering of his life. He had an amazing capacity for accomplishment; he must have sensed all the safe short-cuts, manual and mental; a remarkable memory for details served his concentration upon the essentials; as prolific writer (about 185 titles) his style was concise, though dignified, forceful and clear; and his prodigious reading (hinted by 2545 published abstracts in 10 years) combined insight and discrimination.

Convinced that new ideas are ever needed, his own rich inventiveness was guided by sound judgment. He was sympathetic and receptive to the thoughts of others; when challenge seemed needed he was penetrating and rigorous but unemotional, considerate, and constructive. His breadth of mind and passion for the truth are shown in his subscribing to daily papers of opposite political faith " in order to know what to believe."

Whether in field or laboratory, his quick grasp of the geological truths and his unerring divination of where and how to seek out critical evidence seemed almost magical. But, notwithstanding his great mental powers, Lindgren's career again demonstrates that geology is a science mastered through accumulated increments of experience rather than by spectacular intuition. His eminence had root in a rare intimacy with the field realities and flowered from unremitted wrestling with the basic problems. He exemplified, also, the fact that to be a good specialist in mining geology one must be strong as well in its many collateral fields. Few geologists have accomplished so much in a single branch yet had such scholarly command of the whole science.

Honors came as impressive testimony to his achievements. In the Geological Survey he rose to its highest scientific post. By invitation he taught at Stanford in 1897–98 and at Harvard in 1934, and gave lectures at Columbia, McGill and Queens; honorary degrees were conferred by Princeton and Harvard. He served as President of national and international geological and mining societies and Honorary Chairman of the Sixteenth International Geological Congress. He was a member of the National Academy of Sciences, the American Philosophical Society, Honorary Member of the American Institute of Mining and Metallurgical Engineers, and of many learned societies in Canada, England, Belgium, Russia and Sweden. The Society of Economic Geologists, l'Association des Ingenieurs de Liège, the Geological Society of America, and the Geological Society of London in turn awarded him its medal.

The supreme tribute, unequestionably, was the *Lindgren Volume,* published in 1933, which seeks to generalize the principles of

ore deposition as exemplified in the Western United States. Inspiration derived from Lindgren's leadership is manifest throughout this great collaborative work.

There was nothing fortuitous in Lindgren's entry into the study of ore deposits. Impelling interest and a realization of its scientific fecundity led him to perfect himself for that definite vocation. To it he adhered with singular devotion. His chief concern with statistics and resources was for the needed quantitative perspective. Though his aid was eagerly sought in practical problems, only those commissions were accepted which augured worthy scientific yield. Even his few "holidays" were but occasions for study in new regions, such as his recent examination of volcanoes and fumaroles in Central America. Nor was it due to chance or expediency that he selected the United States as his base of endeavor; rather, to prescience of unequalled and enduring opportunities for research.

But it was sheer good luck that brought this gifted investigator into ore geology at so opportune and critical a stage in its development. Much of the dead-wood of fantastic or vague speculation had already been cleared away by conscientious observation and reasoning, and the broad problem of ore genesis had settled down to an earnest quest for the underlying facts and interrelationships. This quest it was Lindgren's lot to illumine, to systematize and to master in unusual degree.

Lindgren's beloved teacher, Stelzner, sympathetic toward the hydrothermal concepts of de Beaumont, was then developing his devastating reply to Sandberger's tenet of lateral secretion by meteoric waters. We may feel sure that Lindgren carefully surveyed all such doctrines before reaching his own conclusions, which, indeed, were still in formulation when he came to this country.

His first Survey assignment was to aid in the study of the Pacific Coast mercury deposits; next he investigated the Sierra Nevada gold veins. Profoundly impressed by these occurrences, he began to seek explanation of the interconnection between the shallow mercury ores associated with late vulcanism and often

with hot springs and the deeply eroded gold ores occurring significantly in or near intrusive bodies. That the magmatic factor controlled in both he could not doubt, and cautiously but impressively he began to present evidences for this view.

Accumulating experience with many other occurrences permitted, by the end of the century, two fundamental contributions, one on metasomatic processes in veins and holding the seeds of a genetic grouping, the other elaborating and clarifying contact-metamorphic deposits. These objective and evidential papers, emphasizing the vital rôle of intrusive rocks, powerfully affected current and subsequent thought. The problem of interconnection and gradation next found elucidation in his paper on control by physical conditions, which also soundly established the major depth- or intensity-zones. The final step in classification by causative process was attained in his *Mineral Deposits.*

In Lindgren's treatment of these three fundamental concepts: the magmatic source of the great family of ores now classed as hypogene, their varied characteristics and interrelations as determined by physico-chemical environment, and a consistently genetic classification of all ore deposits, lie his greatest contributions. At his hand, each of these strengthened the others. And to this grand framework were added stability and amplification by his many other major contributions.

It falls to an occasional scientist, like Newton, Dalton or Pasteur, so to arrange and augment existing knowledge in his field that it acquires a new unity and value recognized thenceforward as the lasting foundation. In various divisions of geology, Hutton, Murchison and Agassiz are among those who hold such permanent place. While Time's judgment, penetrating the contemporary glow of personal admiration for a master, must decide how enduring and fundamental are his works, even today it is plain that Lindgren's own efforts have left vital and permanent impress on the science of ore deposition. Alluding to the monographic studies early inaugurated by the United States Geological Survey, S. F. Emmons stated in his Presidential Address before the Geological Society of America in 1903:

It was the expectation of those who planned this work that when all the important mining districts of the United States had been thus exhaustively studied, a sufficient story of well ascertained facts regarding ore deposits would have been accumulated to admit of the formulation of a new theory more firmly grounded on a basis of well-established fact than any that had yet been presented.

Is it not Lindgren, long diligent in these very studies, who has done more than anyone else in the world to bring this lofty expectation so far toward gratifying fulfillment? From the vista of the present, it seems incredible that the structure of the future science will not rest on foundations little modified from those which Lindgren in such unique measure has helped to establish.

Lindgren wrought for the glory of science, not for self. He gave encouragement and recognition to his assistants, cooperated inspiringly in establishing and conducting the journal ECONOMIC GEOLOGY, devoted years to teaching others after attaining ripe experience himself, and after his seventieth year dedicated an enormous outlay of energy to make indispensable his creation the *Annotated Bibliography of Economic Geology*. Distinction had to seek him out where he was at work, for he never dallied expectantly in its way. And more than all the decorations and citations, his great compensation was the infinite daily joy of performing his chosen task.

And so, *adios,* Waldemar Lindgren, true and noble knight. Myriad earnest friends temper their sorrow at your death in rejoicing that you lived. Your unassuming and serene gentility, your upright and intelligent citizenship, your generosity, your exquisite humor, and your friendly smile are no more to pass away than are the brilliant and stable results of your researches, your guiding inspiration to many disciples, or the science you loved and served so well. In minds and hearts of generations to come will abide the exalting influence of your great spirit.

L. C. GRATON.

THE GEOLOGY AND DEVELOPMENT OF MILL CLOSE MINE, DERBYSHIRE.[1]

J. G. TRAILL.

ABSTRACT.

This famous old English lead mine works a lead-zinc deposit in Carboniferous limestone, under a shale capping. The orebodies, continuous for 15,000 feet, bear a striking resemblance to the "manto" deposits of Mexico. Ore solutions have taken the path of least resistance from source to surface and the course followed has been controlled by such factors as dip of the strata, jointing and faulting, presence of impermeable lava flows, existence of beds favorable to replacement. Ore is found underneath impermeable lavas and shales, with a vertical height of 100 feet or so, in a remarkable series of interconnecting orebodies, as veins, flats, pipes and caverns, along joints of three systems. Primary minerals are galena (with practically no silver), sphalerite (with 1 per cent cadmium), calcite, fluorite, and barite. Deep secondary mineralization may be accounted for by artesian circulation. Water flow is heavy.

INTRODUCTION.

At the southern end of the Pennines—the range of hills that has been likened to the backbone of England—the Carboniferous limestone has been elevated in a great dome and is exposed as an inlier over an area roughly 20 miles long by 10 miles broad (Fig. 1). The Peak District of Derbyshire, as the region is called, is noted nowadays for its striking scenery, but in the past it was chiefly celebrated for its thriving lead-mining industry. The limestone massif, particularly in its eastern half, is riddled with old lead mines, but for years the only important producer has been the Mill Close Mine, at Darley Dale. In a country notably deficient in non-ferrous metal mines, Mill Close has long enjoyed a renown out of all proportion to the size of the mine.

[1] Presented before the Society of Economic Geologists, New York Meeting, Feb. 14, 1939.

The geology of the mine, however, is particularly interesting and worthy of detailed description. During its long life the mine has been written up more than once. There are the various memoirs of the Geological Survey [3, 8, 11];[2] Stokes made reference to it in 1881 [2]; and in 1896 Parsons gave a very full description of the orebodies then being mined [4]; Stuckey dealt with the mine in a magazine article in 1917 [9]; and it was referred to several times in Varvill's recent paper on Lead Deposits in the Pennine Limestones [17]. The object of the present paper is to bring the subject up-to-date and to give a comprehensive picture of the geological features. The orebodies bear a striking similarity to the "manto" deposits of northern Mexico, and even have some points of resemblance to the Mississippi Valley deposits of the United States. In Derbyshire, as in the United States, the question of the source of the ores is of paramount interest, but the published literature is strangely silent on this point, with the notable exception of Wedd and Drabble's paper [7] on the fluorspar deposits. The memoirs of the Geological Survey contain valuable detailed descriptions of the old mines, but the lack of any reasoned theory about the origin of the ores, other than the statement that they are probably of late Carboniferous or Triassic age, must have contributed to the pessimistic conclusion that few orebodies of any size could be expected below the deep drainage levels. Developments at Mill Close during the past ten years have shown that the ore was deposited from ascending solutions, forced to take a zig-zag, slanting path towards the surface because of the presence in the limestone of a number of impervious lava flows (known locally as "toadstones"). The vagaries of these toadstones constitute one of the reasons why the structural geology of the mine is so interesting. The old theory that the ore was confined to the topmost layer of limestone, above the toadstone, has been exploded with the finding of bonanza orebodies beneath not only the upper toadstone, but several of the lower flows as well.

[2] Numbers in parenthesis refer to bibliography at end.

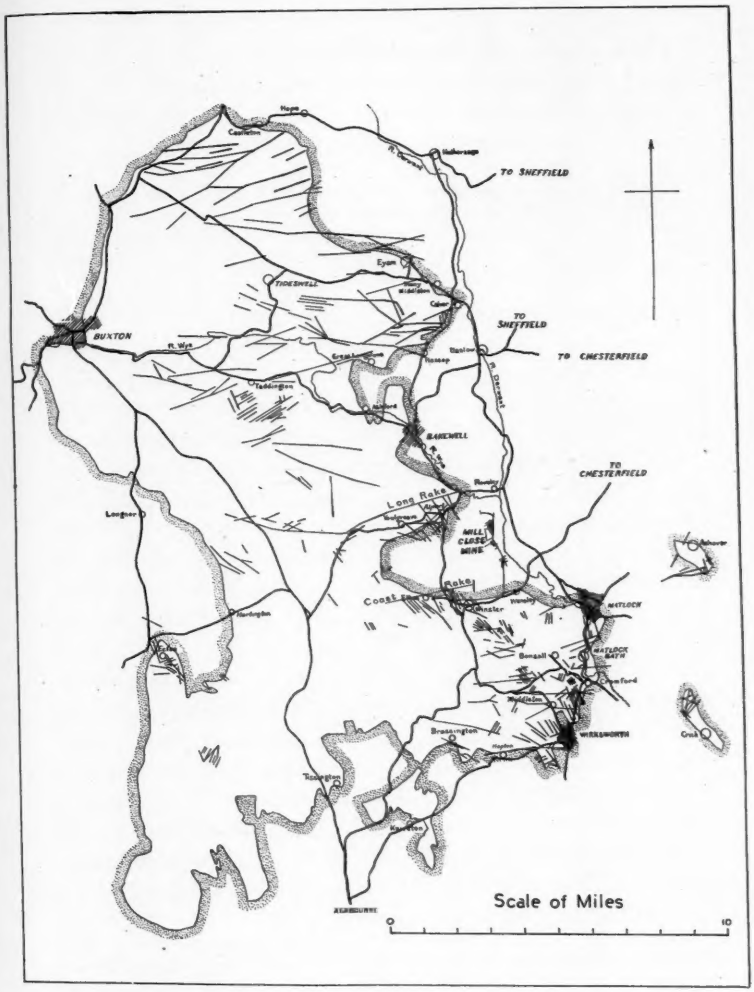


FIG. 1. Map of the Carboniferous Limestone of Derbyshire, showing the principal veins and the location of the Mill Close Mine.

HISTORY.

The history of lead mining in Derbyshire goes back to Roman times, but the Mill Close orebodies, hidden under their capping of shale, probably lay unworked until early in the eighteenth century. The Geological Survey [11] states:

> The earliest operations of the Mill Close Mine may be 200 years old, and probably started as a continuation under the Yoredale Shales, of a group of surface workings on veins traversing the limestone outcrop south of Wensley village; these have ever since been followed progressively further north under the shale covering.

The London Lead Company, popularly known as the Quaker Company, was, during the eighteenth century, actively engaged in lead mining in many parts of England. A recent paper by Dr. Raistrick [18], of Newcastle, gives a detailed account of the Quaker Company's work in Derbyshire. It seems that the Quakers commenced work in 1720 on a number of veins in the neighborhood of Wensley and Winster, bought the old Mill Close Mine in 1743 for £1,050, and drove two " soughs " or drainage levels westwards from the River Derwent to unwater the bottom levels of the mines at Wensley and Winster. The first of these drainage levels was called the Mill Close Sough and the second was the better known Yatestoop Sough, which took 21 years to drive and cost £30,000. Reference to the longitudinal section (Fig. 3) will show how the strata dip steeply north of the Mill Close Sough, taking the ore-bearing limestone rapidly underfoot. A steam pumping engine was installed in 1748 to enable work to proceed below the adit level, and continued in operation until 1764, when work was stopped. The company was by this time cutting down on its operations in all areas except the north of England, and by 1778 all activity in Derbyshire had ceased.

According to the Geological Survey [11],

> the mine subsequently lay idle for about 100 years, but it was reopened in 1859 by the late Mr. Wass. In 1861 ore began to be raised and has continued uninterruptedly to the present day, except for two years (1875–77) when the mine was temporarily drowned out. After Mr. Wass's death in 1886, his trustees took over the mine until 1919.

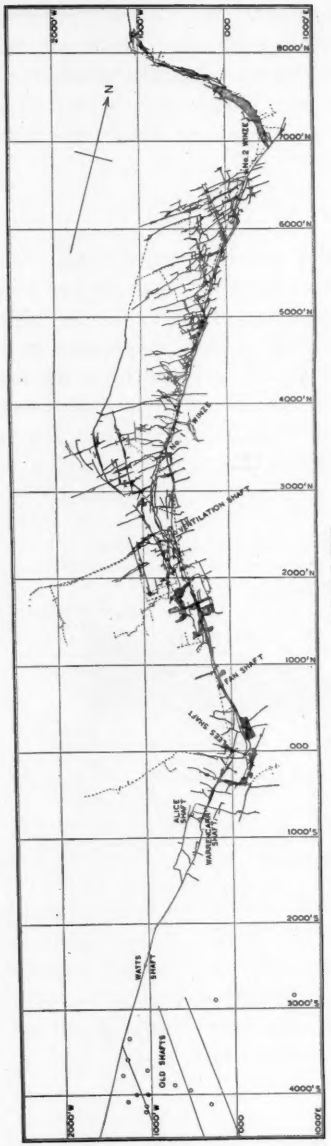


FIG. 2. Plan of Mine Workings. The dotted lines represent development crosscuts and drifts not in ore.

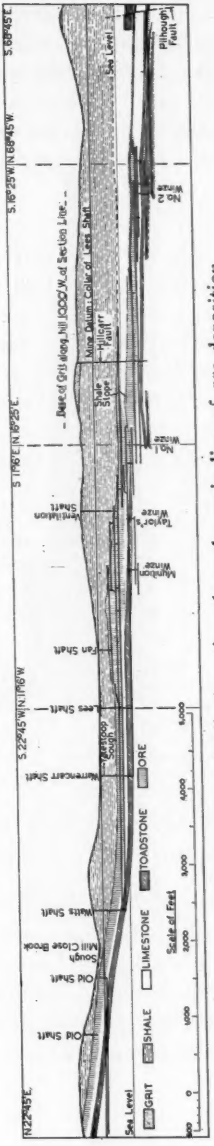


FIG. 3. Longitudinal section along the main line of ore deposition.

The present owners, the Mill Close Mines, Limited,[3] acquired the property in 1922 on the recommendation of the late Dr. Malcolm Maclaren, and have worked the mine continuously since that time. Operations in recent years have been on a substantial scale; about 10,000 tons of ore are mined per month, and mine and smelter employ over 700 men.

PRODUCTION.

The mine has produced, since it was reopened in 1859, over 400,000 tons of lead concentrates averaging about 82 per cent lead. More than half of this total appertains to the last nine years (Table 1). Some 30,000 tons of zinc concentrates have also been produced, and the increase of zinc content in the ore has been so marked since 1935 that the current production of zinc concentrates actually exceeds that of lead concentrates. Fig. 4 shows in graphical form the production year by year since 1904.

TABLE 1.

PRODUCTION, MILL CLOSE MINE, 1861–1939 (LONG TONS).

Period	Lead Concentrates		Zinc Concentrates Total
	Total	Annual Average	
1861–1887	36,035	1,440	?
1888–1893	±15,000	±2,500	?
1894–1903	42,052	4,205	?
1904–March, 1920	67,394	4,190	7,516
Apr. 1920–March, 1929	24,565	2,730	±1,600
Apr. 1929–March, 1938	222,041	24,670	21,573
	407,087		30,689

STRATIGRAPHY.

Dr. Malcolm Maclaren said of Mill Close that the geology of the district had a much more obvious bearing on ore-deposition than is generally the case with metal mines. For that reason a fairly detailed account of the local geological features is necessary for a complete picture of the ore occurrences. Much has

[3] Technical control lies with the New Consolidated Gold Fields, Ltd.

been written about the Carboniferous limestone of Derbyshire since the publication in 1811 of Farey's comprehensive report [1]. The memoirs of the Geological Survey dealing with North Derby-

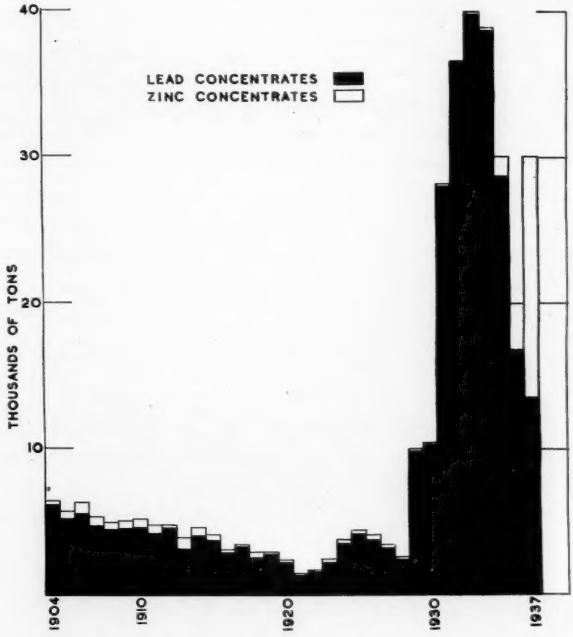


FIG. 4. Production Graph. 1904–1937.

shire [3] and the Northern Part of the Derbyshire Coalfield [8] describe these areas; and a valuable paper [15] by Professor Fearnsides and others, published in 1932, summarizes all the information available at that date. The writer hopes shortly to publish some notes on the local stratigraphy as seen in the mine workings, and on the relations of the various toadstones that have been discovered at Mill Close during the past few years. The stratigraphic sequence given in Table 2 has been simplified from these notes.

TABLE 2.

SIMPLIFIED STRATIGRAPHIC SEQUENCE.

Mill Close Mine.

System	Series	Formation	Thickness in Feet	Character of Rocks
Upper Carboniferous	Millstone Grit	Kinder Scout Grit	150–200	Thickly-bedded sandstones; coarse grits.
		Grindslow Shales	±700	Formerly classed as Yoredale Shales and Grits.
		Shale Grit		Black, argillaceous shales with thin grit band, and a bed of black limestone.
		Edale Shales		
Lower Carboniferous	Carboniferous Limestone Series	First Limestone	146	31′ of thinly-bedded, dark, cherty limestone—the "Black Beds."
				115′ massive, white limestone; darker toward base; numerous shell beds.
		Upper Toadstone	0–76	Amygdaloidal dolerite lava.
		Intermediate Beds	14	Light limestone with shaley partings and shelly bands.
		Alport Toadstone and Intermediate Tuff	1–90	Basalt with some amygdaloids, passing into thin, green tuff.
		84 Limestone	35	Coarse-grained, nearly white limestone.
		103 Toadstone	0–22	Amygdaloidal basalt lava.
		Second Main Limestone	132–155	Base of dark, thin-bedded cherty limestones, merging above into massive, light limestone. A sudden change to dark, thin-bedded, shelly and coralline limestones, with chert, grading upwards into massive light limestone again.
		Upper 129 Toadstone	1–28	Hard, dolerite lava.
		129 Limestone	40	Very coarse-grained, pure, light-color limestone.
		Lower 129 Toadstone	10–26	Hard, dolerite lava.
		10-Foot Limestone	10–31	Very coarse-grained, pure, light-color limestone.
		144 Pump Station Toadstone	+50	Hard, amygdaloidal, basalt lava. Base not exposed.
		Limestone	+1000	With toadstones?

It will be seen that the divisions in the Carboniferous Limestone Series are based on the "toadstone" sheets found at various horizons rather than on fossil contents. One reason is that the stratigraphy of the Matlock district, and particularly of the limestones now being exposed at the lowest levels of the mine, has not yet been worked out in detail by palæontologists. Another reason is that these toadstone lava flows are of the greatest importance in determining the course of the ore.

The Edale Shales.—This is the name now accepted for the

shales that rest upon the Carboniferous limestone in Derbyshire, which used to be classed as belonging to the Yoredale Group. They are black, argillaceous shales with thin bands of black, bituminous limestone, particularly near their base. Their significance from an economic point of view lies in their impermeability. The result is that they formed an effective dam to ascending solutions, which were compelled to seek a rising path towards the surface along such channels as were available *underneath* the shales. An objectionable feature of the shales, from a mining point of view, is that they give off quantities of methane, making safety lamps necessary in the upper levels of the mine and making good ventilation essential.

The Carboniferous Limestone has been very fully described by Bemrose [5] and by Wedd and Drabble [7], as well as by Gibson and Wedd [8]. Wedd and Drabble estimate the thickness of the limestone with its intercalated toadstone flows to be at least 1,500 to 1,700 feet. The base is not exposed, and whether it rests upon the Old Red Sandstone or on the Silurian is a matter of conjecture. Moreover, it is known from fossil evidence that the thickness of Carboniferous limestone that outcrops in Derbyshire represents only the upper part of the series as exposed in south-western England, near Bristol.

The Toadstones.—The most striking feature of the limestone series is the way it is divided up into alternate layers of limestone and toadstone (Table 2), but the latter do not, as was formerly supposed, form continuous sheets over the whole district. Individual toadstones show pronounced variations in thickness and die out within a few miles. The largest known flows may attain a thickness of 100 feet or more, and have a horizontal extent of five or six miles. Beyond the edge of a flow proper its horizon is marked by a thin "wayboard" of shale or tuff, which may extend for miles. In the 400 feet depth of limestone penetrated by the Mill Close workings, at least seven thick toadstones and seventeen such wayboards have been recognised, and it is known from the evidence of other districts that lavas occur in the limestone series down to a depth of about 700 feet. They are ex-

tremely irregular in occurrence, and there must be dozens of hidden volcanic necks scattered throughout the district, besides the few that outcrop. A widespread igneous magma probably underlies the whole region, and one can imagine that, during the time throughout which the uppermost 700 feet of limestone were being deposited, there was intermittent volcanic activity over a fairly large area. A period of quiescence would be followed by an ejection of lava or tuff, forming a bed of toadstone neither very extensive nor thick. This outburst would be followed by another period of quiescence, which in its turn would be succeeded by another outpouring of lava at a different place. Some of the "squirts" from the magma below failed to reach the surface and formed the sills described by Dr. Bemrose [6]. No sills have as yet been encountered at Mill Close.

It would be pertinent at this stage to summarize the proofs that the toadstones of Mill Close are lava flows and not sills.

The principal evidences are:

(*a*) Their wide extent in comparison with their thickness.
(*b*) No transgression of overlying or underlying beds.
(*c*) Abundance of vesicles in the upper half.
(*d*) Recognisable pillows, showing that the lavas were laid down under water.
(*e*) Marmorization of the underlying limestone, to a depth of 1 to 3 feet, but none above.
(*f*) The development of a shell bed, or a bed of nodular limestone immediately above a toadstone, pointing again to submarine conditions.
(*g*) A marked change in the character of the limestones overlying some toadstones, indicating a change in the conditions of sedimentation coinciding with the toadstone horizon.

Two of the flows (the Upper and Lower 129 Toadstones) seem to have been extruded, in places at least, on a partly eroded beach, but all the others are submarine lavas, and good examples of pillow structure are encountered.

Regarding the petrography of the toadstones, the Mill Close lavas may be described either as basalts or as olivine dolerites, depending on their structure. Those having a doleritic or subophitic texture are olivine dolerites; the fine-grained, black varieties are basalts. Most of them—not all—are highly vesicular, and somewhat altered.

The toadstones tend to weather at their upper and lower surfaces into clay, especially where they have been exposed to the action of mineralizing solutions. They form, except where cut by fault fissures, impermeable layers similar to the shales in their effect on ascending mineralizing solutions, so that each toadstone is the roof of a potential ore-bearing horizon. Of the six toadstones shown in Table 2, ore has been found in turn beneath all but the lowest, which has not been bottomed.

The Limestones.—For a comprehensive account of the limestones, the description given by Wedd [8] could not be bettered, so it is given here in full:

> The Dibunophyllum zone (D of Dr. Vaughan's classification) alone is represented. The topmost beds of the limestone often show . . . a gradual upward transition into the shales. The line of division between the limestone and shale formations therefore becomes in places rather indefinite. The higher beds of the limestone always contain layers of tabular or nodular chert. . . . Occasionally two of these bands by approximating to each other betray a lenticular bedding not otherwise discernible.
>
> The greater part of the limestone (except the upper beds) . . . consists of a pale rock, creamy white, light bluish-grey or fawn-colored. It is a comparatively pure limestone where not subsequently dolomitized or silicified.
>
> In microscopic structure it ranges from a fine-grained, calcareous mud, with sponge spicules and foraminifera, through microgranular and microoolitic types to more coarsely granular limestone with rolled shell fragments and little pellets of detrital limestone. Parts of it have a coarsely crystalline appearance owing to the inclusion of innumerable calcite-organisms, chiefly crinoid ossicles. The dark parts of the limestone probably owe their color to argillaceous impurity, and it is often noticeable that this color is deeper near shale bands, and that the rock for a few feet above a toadstone has a much darker tint than the succeeding beds.
>
> Dolomitization, which does not follow stratigraphical lines . . . locally involves great masses of the limestone over a considerable area. The more dolomitized limestone generally takes a light brown or yellowish hue.
>
> Minute quantities of petroleum and bitumen sometimes partially fill the cavities of brachiopods. In the case of corals, it is chiefly in the more dolomitic rock that the spaces between the tissues are hollow and contain specks of bitumen.
>
> While the limestone and its fauna suggest formation in a comparatively shallow sea, occasional evidence is afforded of the proximity of land, *e.g.* by the local occurrence of an underclay with calamites above the upper lava, and of a thin coal and underclay in the higher beds of the limestone.

The foregoing description applies to the Matlock district, a few miles southeast of the mine, but in general it is equally applicable

to the Mill Close district, with one or two important differences. In the first place, the Mill Close sequence contains not one, but three distinct series of cherty limestones. The uppermost, which lies immediately below the shales, at the top of the First Limestone, corresponds to the one mentioned by Wedd. The other two are both found in the Second Main Limestone. Each shows a gradual transition upwards from thinly-bedded, dark, cherty limestones into massive, light-colored beds. The upper of the two contains numerous bands of dark, shelly and coralline limestones in addition to the layers of chert nodules.

The dolomitization mentioned by Wedd has not been found at Mill Close. Many samples suspected of being dolomitic have been analyzed but always with negative results. The silicification referred to—which involves the development of microscopic crystals of secondary quartz throughout the limestone—is also unknown in the Mill Close district.

STRUCTURE.

The broad anticline or dome that forms the dominant structural feature of the limestone area has already been mentioned. In the Mill Close district the anticlinal axis strikes roughly NW–SE, and it was as a result of adjustment to folding in this direction that the northwest system of gash-veins was developed. Dr. Maclaren assigned the north system to the same folding movement, at a slightly later period.

Later still, a minor north-south crumpling along the eastern flank of the main dome formed a series of broad folds, striking E–W, and gradually dying away westwards in the direction of the main N–S anticlinal axis.

Dr. Maclaren said: It was probably as an end result of this transverse crumpling that the great "rakes" (E–W cross veins) of Derbyshire were formed. This vein-system is obviously much more persistent in depth than the two gash-vein systems already mentioned, since an inspection of the geological map indicates that many of these rakes, especially in the north, still show on the fairly deeply-eroded crest of the anticline while the members of the shallower NW and N systems that were probably originally there are eroded from the crest of the anticline and are confined to the borders of the shales, where erosion has naturally been less extensive. . . . The average strike of the rakes is ENE–WSW, parallel to the minor folding. They are generally strong faults.

The Mill Close workings are located in the southern limb of one of the minor E–W synclines, between the Coast Rake and the Long Rake, where the orebodies have lain hidden underneath their capping of shale and grit. The local structure, then, is that of a trough pitching gently eastward, with a length of four miles from its western rim to the Derwent River and with a breadth between the Long Rake and the Coast Rake of 2½ miles. That the syncline was far from symmetrical was not apparent at the time Dr. Maclaren made his examination. At a distance of two miles north from the Coast Rake, the strata still dip northwards, so that the eventual rise towards the Long Rake is bound to be rapid. This circumstance has invalidated Dr. Maclaren's conclusions, which were, briefly:

(1) That the mineralizing solutions rose from the south; (2) that the synclinal axis of the trough (which he supposed to lie between Lees Shaft and Ventilation Shaft) was the most likely line along which to prospect; (3) that orebodies would be confined to the First Limestone; (4) that other NW joints parallel to the Mill Close Fault and west of it would be found to carry ore.

Although subsequent work has proved Dr. Maclaren to be wrong, his reports are still a model of logical reasoning on the data available at the time he made his examinations (1920 and 1923), and they are still referred to frequently by the mine staff.

Joints and Faults (Fig. 5).—The limestone, as a result of the folding just described, is honeycombed with joints which, however, fall naturally into three systems. The first is the NW system of gash-veins, ranging in strike from NNW to WNW, and the second is the north-striking system. "The third system" to quote Dr. Maclaren again "has a general strike of ENE–WSW, with minor variations from this general direction. This system comprises by far the greater number of veins, ranging in strength from the great rakes (Long Rake and Coast Rake) down to the numerous 'scrins' or stringers which intersect the members of the other two systems." All are potential ore-carriers, and the main

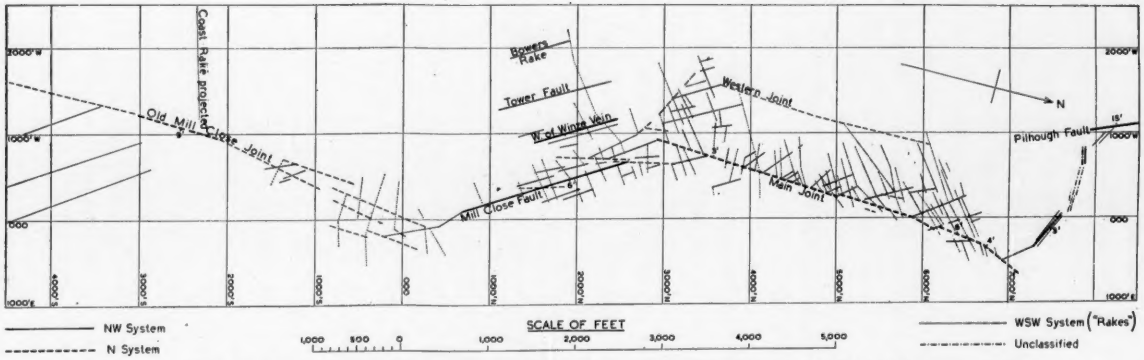


FIG. 5. Sketch plan of the joint systems at Mill Close. Known faults are indicated by heavy lines, and the throw in feet is given, where known.

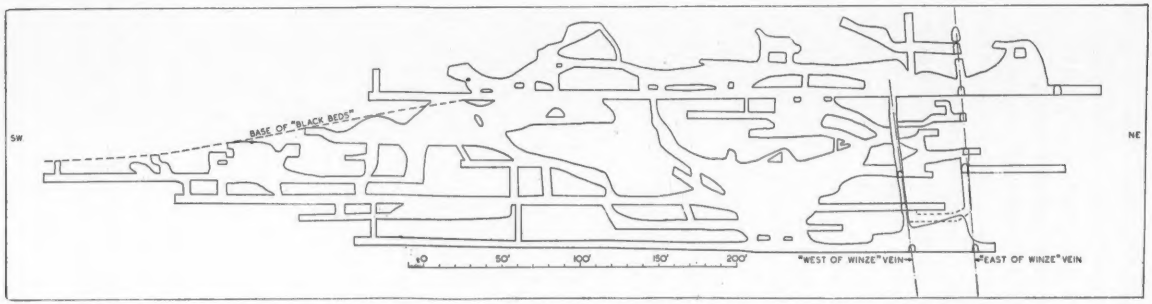


FIG. 6. Longitudinal section of orebody in Squares E7 and E8 (N 2175, W 930 to N 1965, W 1365).

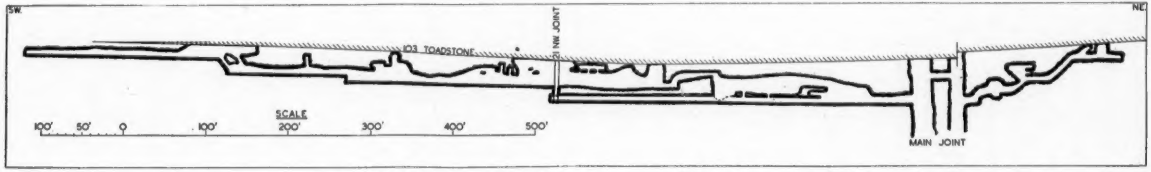


FIG. 7. Longitudinal section of 22 SW stope (N 6615, E 425 to N 6025, W 995).

line of ore deposition makes several changes from one system to another in its course from north to south, as will be seen from Fig. 5.

Most of the joints, where not subsequently enlarged by solution or mineralization, are mere cracks or joint planes in the limestone, but a few are true faults with vertical displacements of 6 to 8 feet, or, exceptionally, 15 feet. Fig. 5 indicates the throw of the known faults in the mine. It is interesting to note that the majority of the faults belong to the N system, a few to the NW system, and none to the rake series. Formerly, a complicated system of block faults was hypothesized to explain an apparent downthrow in one of the toadstones, but a detailed examination of the district in question has shown that there are two separate toadstones 35 feet apart and that the supposed faults do not exist. Faulting may be said to be relatively unimportant at Mill Close, but such faults as do exist have an economic importance because of the relatively easy path they present to mineralizing solutions —easy, that is, in comparison with those narrow joints on which no movement has taken place. Open fissures are much less common in toadstone than in limestone, partly because of the insolubility of the igneous rocks, partly because of the way they tend to break less cleanly and then decompose into clay; but, nevertheless, several instances have been found at Mill Close where the existence of an open channel on a fault has permitted ore-solutions to rise from below a bed of toadstone to a higher horizon.

That most of the faults seen underground have a horizontal as well as a vertical throw is indicated by the presence of horizontal striæ on their walls. The extent of the horizontal movement is not believed to be great, having regard to the relatively undisturbed nature of the beds with their gentle dips, and the small vertical displacements on the faults. In several cases this seems to be borne out by facts. For example, in a winze below the 129-fathom level, north of No. 2 Winze, the Lower 129 Toadstone was found to be of equal thickness on the two sides of the fault (Fig. 8). Since the toadstone hereabouts shows rapid variation

in thickness, any considerable horizontal movement along the fault would show up a difference in thickness of the toadstone on the two sides of the fault. As no difference is found, the probability is that the horizontal throw is not great.

Dr. Maclaren mapped and described some large faulted blocks of Millstone Grit at the surface, and showed them to be due to landslips, since two [4] of the " faults " were found underground to have no displacement. This is in line with the explanation given by the Geological Survey in the North Derbyshire Memoir [3], as follows:

> Many cases have been noticed at the foot of hill slopes formed of soft shales and capped by massive sandstones. Frost, springs, and underground streams soften and carry away the shales, and huge masses of the sandstone, thus deprived of their support, break off along joints, and slide or topple down into the hollow below.

OREBODIES.

General Features.

Much has been written about the irregular forms assumed by the limestone replacement deposits of Derbyshire in general, and of Mill Close in particular, but it was not until Varvill's paper [17] appeared in 1937 that any account was given of the course followed by the ore.

The old accounts contain much space devoted to the question of whether or not the ore was cut off in depth by the toadstones. Generally it is, but the occurrence of ore in some mines *underneath* the toadstone was hard to explain. It seems strange nowadays that the " old men," knowing how impermeable the toadstones were, should not have realised that their ore deposits lay on a slight slope, and were fed from the lower end. Much useless development has been carried out, from ancient times up until quite recent years, in searching for the downward extensions of known orebodies vertically underneath them, often below a thick lava flow. Thousands of feet have been driven on barren joints which, less than 200 feet higher, were the locus of rich orebodies.

[4] The Chapel " fault " and the Hillcarr " fault." The third side is bounded by the Tower fault.

This in spite of the fact that the miners have known, for more than sixty years, that the way to find new ore is to follow the known orebodies laterally wherever they may lead. By far the most important characteristic of the ore is its remarkable continuity, yet this notable feature has never been commented on, either in the Memoirs of the Geological Survey or in the various papers already mentioned. It has already been stated that ore has been found beneath no fewer than five successive toadstones, as well as below the shales. Yet, through all these steps, and for a distance of 15,000 feet from the outcrop to the far northwest end of the mine, the orebodies, though ramifying, have been continuous. Every ton of ore that has been mined has come from the main orebody or from one of the numerous connecting branches. Even orebodies that have been discovered by crosscutting—and they are few—have been found afterwards to join up with known ore.

In an article [12] that appeared 13 years ago and which was described by Spurr [13] as "the most important single paper on economic geology, both from the practical and the theoretical standpoint, which has been published for many a long day," Prescott outlined the characteristics and underlying principles of the limestone replacement deposits of northern Mexico, and showed how erroneous were the ideas regarding their nature that had prevailed up to that time. He attacked the commonly accepted statements that the ore was found in cavities in the limestone joined by narrow, almost imperceptible cracks, which, if followed, would lead from one orebody to another, and that the orebodies were enlargements of these fissures, generally at the junctions of two or more of them. The errors and misconceptions he exposed are identical with those that have been rife in Derbyshire, and the picture he substituted as the true one—which soon came to be generally accepted, with only slight modifications—might have been written of Mill Close, so exactly does it fit the conditions. For example, Prescott emphasized the continuity of the orebodies and their rising course, from where they enter the favorable limestones at depth to where they reach the

surface, or until they gradually become extremely attenuated. The upward course of an orebody, he said, is controlled by the following factors: (*a*) favorability of certain limestones, due to composition or texture; (*b*) posture of the beds; and (*c*) premineral fissures. Another principle, difficult of corroboration in the case of such a ramifying deposit as Mill Close, is that the cross-section of an orebody varies gradually by small increments, and generally increases slightly with depth.

Prescott made one rule that does not apply at Mill Close. He said that the analysis of each orebody was distinctive and, broadly considered, invariable, and gave interesting examples of how some "mantos" were traced to their parent "chimney" by a comparison of representative analyses. That this is not true of Mill Close may have something to do with the great range of the Mill Close manto—15,000 feet as compared with mantos up to 12,000 feet long described by Prescott—or it may be due in some obscure way to the presence of the toadstones, but in any case it does not affect the striking similarity in structural features between deposits so far apart.

Prescott stated that no replacement deposit in his experience followed a single fissure throughout its whole length, but that orebodies would leave one fissure for another, and would in places follow an irregular course, apparently without control. He maintained that the importance of fissures in determining the course of the ore had been greatly exaggerated, and that their role in primary deposition—as distinct from their function as channels of secondary mineralization—was a very minor one. Now, the Mill Close manto—for its resemblance to the Mexican deposits entitles it to the name "manto"—jumps from joint to joint; even the main line of deposition changes direction four times. In this respect it falls in line with Prescott's observations, but fissures evidently play a rather more important part in Derbyshire than in the Mexican deposits. It is likely that, had the impermeable toadstones not been present to check the upward flow of the mineralizer, it would have risen directly along the convenient upward path offered by the open fissure, until it met the overlying shales.

Three years after the publication of Prescott's article, there appeared Fletcher's equally important one [14], dealing with the same district. It is the present writer's belief that this latter article supplies the key to the origin of the lead deposits in Derbyshire. This is sufficient justification for setting down at length a number of extracts from Fletcher's article, as follows:

> A lead-silver orebody in its manto and precedent phases always follows the course of least resistance from its igneous source to the surface.
>
> Should the igneous intrusion be truly batholithic and not penetrate to the surface, the mineralizer will ascend the most opportune simple break or break intersection in the limestone, in vein or chimney form, until it encounters a favorable horizon. It will then follow this favorable horizon, displaying in its passage through it the characteristics of a manto deposit, until it arrives at the surface. . . .
>
> In the manto phase the stratum chosen for invasion by the mineralizer is chosen because of its texture or composition and the course of the mineralizer through that elected stratum is determined by folding, faulting, and fracture. . . .
>
> Factors which reduce resistance to the invading force of the mineralizer in the favorable horizon are structural factors, and, in the order of their importance, are fracture, folding, and faulting. In the thicker mantos, the evidence of control may have been obliterated in certain formations by the replacement that occurred along its course, but the control almost certainly did exist and did determine the course of the orebody in its migration through the favorable horizon.
>
> The truth is that fractures, faults, and structure control the course of mineralization within the favorable horizon. They may permit escape from that horizon at any point, but only at one point do they permit access to it.
>
> Should more than one favorable horizon exist, these same fractures may again become of importance where they traverse those horizons and may again control channels of mineralization in them.
>
> These manto orebodies travel uphill and so are likely to outcrop in the anticlinal elements of structure. Anticlinal folding . . . leads to the development of fractures and faults which furnish the channels for ore deposition.
>
> Faults along which considerable displacement has occurred are likely to act as dams in the ore channel and deflect its course. It is a fact not realized by most geologists that at least 90 per cent of such faults in the Mexican Cordillera are pre-mineral, and hence do not mechanically offset the orebodies that abut them.
>
> A fault is more likely than a fracture to be the channel of entry used by the mineralizer in reaching the favorable horizon. Being a plane of displacement, a fault cuts deeper than a fracture, which is only a simple break. Summarizing, a favorable bed, often dolomitic, usually in an anticlinal attitude and traversed by fractures, constitutes the typical environment of a silver-lead orebody in its manto phase.

Fletcher goes on to show that the manto phase represents only

one element in a unity, of which the other members are, in descending order (1) a vein or chimney; (2) a contact deposit; and (3) a breccia or fracture deposit in an underlying igneous intrusive. It is extremely unlikely, on account of the heavily watered nature of the limestone in Derbyshire, that mine workings will ever penetrate deep enough to find out whether these same conditions exist there. Even the presence of a batholithic intrusion can only be conjectured, but Rastall says [10, p. 303]:

> It must be remembered, however, that the Pennine Chain is an anticlinal structure, which must be somehow supported from below, and this support may be afforded by the intrusion of a granitic bathylith along the axis of the anticlinorium.

The Orebodies in Detail.

The First Limestone, South of Lees Shaft.—The little that is known regarding the orebodies south of Watts Shaft indicates that the ore was found in a number of joints, in the white limestone underlying the black beds. The principal joint here belongs to the N-striking system, but a number of subsidiary NW joints lying east of it also seem to have carried ore.

North of Watts Shaft the steep dip of the beds carried the ore-bearing horizon rapidly deeper. The ore seems to have been mainly confined to the same N-striking fissure as before, and near the top of the same white portion of the First Limestone. At both Watts Shaft and Warrencarr Shaft it has been proved that no ore exists in the fissure below the toadstone. Near Warrencarr Shaft, where the dip flattens out, is the first instance of the branch orebodies that become so important farther north, with ore wholly or partially filling solution cavities along crossing joints.

Between Warrencarr and Lees Shafts, where the beds are flat, there is an extensive development of ore in joints of all three series, forming a sort of crossover from the N-striking main joint to one belonging to the NW series and known as the Mill Close Fault.

The First Limestone, North of Lees Shaft.—North of Lees Shaft, the ore follows the NW-striking Mill Close Fault, with the

beds beginning to rise again. This rise is the beginning of a small anticline (Fig. 3) and is accentuated by a thickening of the limestone a little farther north, caused by a local unconformity at the shale-limestone contact. In this zone, which is the one described by Parsons, most of the ore was found in the main vein, but parallel and crossing joints, "flattings," and caverns lined with ore became increasingly important about 1,500 to 2,000 feet north of Lees Shaft. The flats were evidently formed by the solution of especially favorable beds of limestone, particularly where overlain by an impervious "wayboard." They did not persist far from the parent fissure. Some of the caverns here were quite extensive, with calcite and ore minerals lining the walls and roof, and blocks of limestone and broken gangue covering the floor. Parsons says that the caverns supplied much of the best ore, but this is not in accordance with the evidence of the old miners, who assert that the masses of calcite and broken limestone seriously lowered the grade of ore from these caverns. The main vein varied considerably in width and in character, in places assuming a banded structure and in other places widening into caverns. Where banded, the order of deposition of the minerals, according to Parsons, was: sphalerite, fluorite, barite, galena, calcite, pyrite.

On the Mill Close fault the ore persisted up into the black beds, and even into the shales; in general, the greatest distribution of ore occurred just below the black beds. At Lees Shaft the ore bottomed about 50 feet below the black beds; farther north the height of ore was greater, but on crossing joints the bottom of the ore rose as it receded from the main vein. Fig. 6 shows a section of a typical joint of the SW system, with the base of the ore rising towards the southwest to meet the dipping roof until the ore practically dies out in that direction.

Opposite Ventilation Shaft the SW "scrin" called the Chapel "fault" formed an important crossing vein. North of this, ore was mined in a network of little SW and NW veins and died away northwards along two parallel joints of the N-striking system, called the Main Joint and the Western Joint respectively. One unusual feature of this area deserves mention. This is the

so-called "shale stope," in which ore was worked in a narrow fissure up into the shales for 100 feet or more before it pinched out. The joint belongs to the SW system, and may be observed on the plan at co-ordinates N 4000, W 1000. It coincides with the axis of a minor anticline, which may account for the fissure in the shales. When the mineralizing solutions reached the crest of the anticline under the shales, their strong ascensive urge would play its part in forcing the solutions up into the narrow crack in the shales.

The 84 Limestone and Second Main Limestone No. 1 to No. 2 Winze.—By 1929 practically all of the known ore in the First Limestone had been, or was almost, worked out. There remained only a stretch of good ore in the floor of the bottom (73-fathom) level, at co-ordinates N 3400, W 770. A winze was sunk in this ore against a heavy flow of water, and it was found that the toadstone had died out, and that the ore persisted northwards at a lower level, capped by a thin bed of tuff (the Intermediate Tuff). Bonanza ore was followed along the N-striking Main Joint from No. 1 Winze to beyond No. 2 Winze, a distance of 4,000 feet. For the first 2,000 feet, the Intermediate Tuff formed the roof, and then another lava flow (the 103 Toadstone) came in from the northeast, at a horizon 35 feet lower, and formed the roof of the ore from there northwards. The walls of the vein were very irregular, but the average width of ore in the Main Joint was about 15 feet. The bottom of the ore rose in a gradually-ascending, fairly regular line from No. 2 Winze back southwards to No. 1. Where topped by the 103 Toadstone, the ore had a height of about 85 feet; farther south, below the Intermediate Tuff, it was 120 to 130 feet high.

In this latter stretch there was an interesting development of flats or "flattings" off the Main Joint near the base of the ore. These flats were found, as a rule, only on the western side of the Main Joint, and extended 50 feet or more from the parent vein, giving the orebody an L-shaped cross-section. The flats were found in a bed of coarse-grained, pure limestone capped by a thin wayboard, and Varvill has shown how their shape was influenced

by the jointing of the limestone. These flats form a good example of the favorability or partiality of certain beds, to which reference will be made later.

Concurrently with the development of the Main Joint itself, ore was being opened up in a number of branch veins on a series of "scrins" or "rakes" (*i.e.* SW-bearing joints) west of the Main Joint. These branch veins had a width of about 6 feet and a height, where they left the Main Joint, of about 60 feet. The same limiting bed that formed the roof of the ore in the Main Joint also acted as the capping for these branch orebodies. The base of the ore was irregular, but rose gradually towards the southwest until it reached the roof, forming in longitudinal section, an elongated wing-shaped orebody, for which Varvill [17] has coined the name "wing deposit." Some of these wing deposits attain a length of 800 feet, or in extreme cases 1,300 feet, and the regularity with which they occur is remarkable. All did not contain equal quantities of ore: some have been found to extend from the irregular floor line up to the limiting roof bed as sheets of practically solid vein-material, with only a few pillars of unaltered limestone; others only touched the limiting bed in places, and contained a large proportion of limestone in large and small pillars; others again consisted of nothing more than a series of ramifying "pipes." Fig. 7 is a longitudinal section of one of the longer of these rakes.

The 103 Toadstone, which overlies the area about No. 2 Winze, dies away to the southwest, and these branch orebodies, which have become rather attenuated by the time they reach the edge of the flow, jump up 35 feet to the Intermediate Tuff and take on a new lease of life. Work is still proceeding southwestwards on rakes that were first discovered more than four years ago. The area as a whole has been responsible for important tonnages of ore.

Complementary to the rakes, and forming a sort of "backbone" pattern, are the northwest series of joints, shown on the plan. The ore is similar, but the wing-shaped form characteristic of the rakes is missing. The bottom of the ore along these north-

west joints follows an up-and-down line, the lowest points corresponding with the intersections of the (SW) rake joints.

A few of the rake joints carry ore for a short distance northeast of the Main Joint, but the amount of ore developed on this side is negligible compared with the large quantities found on the western side. This remarkable feature is difficult to explain, but it may simply be that the mineralizing solutions, flowing upwards from north to south, found it easier to branch off into the diverging SW joints than to make the acute turn to the NE.[5] The widespread distribution of ore in the SW and NW joints (*not* faults) west of the so-called Main Joint (which is really a fault) is contributed to by three factors, namely: (1) The posture of the overlying toadstone beds in this area permitted mineralizing solutions to rise to the southwest as well as along the Main Joint to the south; (2) The NW and SW joints were well developed, providing the necessary channels for solution and infilling; (3) The 84 Limestone and the upper part of the Second Main Limestone are both pure, rather coarse-grained limestones, very susceptible to replacement. Had there been, instead, a thinly-bedded, dark, siliceous limestone, the area of ore-deposition would have been much restricted, possibly to the Main Joint itself.

North of No. 2 Winze, no southwest branches have been found to date. The ore followed the north-striking Main Joint for some 600 feet, but as a narrow fissure-filling, with a gradually rising base line. Four years ago, it became apparent that the orebody was dying away in this direction, and a stretch of ore in the floor of the 112 fm. level was selected as a likely looking spot for the downward continuation of the ore towards its source. Ore was followed in a winze down through the Upper 129 Toadstone to the next limestone bed, the 129 Limestone (Fig. 8).

The 129 Limestone, No. 2 Winze Northwest to Pilhough Fault.

[5] This theory finds some support in the distribution of branch orebodies in the First Limestone between Lees Shaft and Warrencarr Shaft. The branch veins here cut across the main vein at right-angles, and branch orebodies are about equally well developed on the two sides. The same argument holds true of the area south of Ventilation Shaft, when it is taken into account that the main north-south ore stream was here split between several joints of the NW system, forming a zone 200 feet wide, with ore in crossing veins fairly well developed on both sides of this zone.

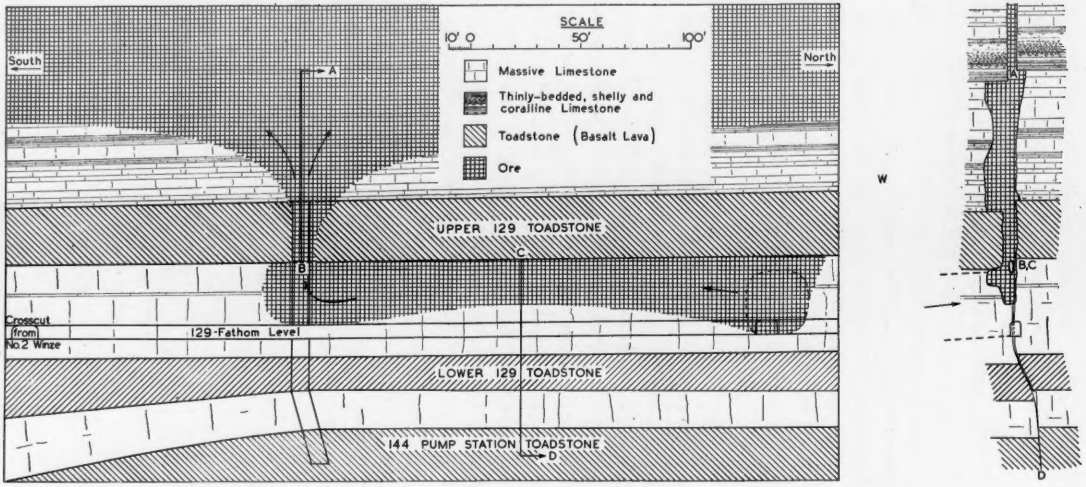
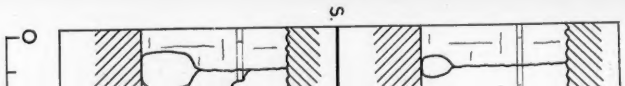


FIG. 8. Longitudinal and cross sections of the main orebody, just north of No. 2 Winze, showing the pipe of ore beneath the toadstone, the "vent" in the toadstone and the vein above. Note the abrupt contraction of width at the point "A" in the cross section, where the vein enters the unfavorable shelly and coralline limestones.



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—From the winze just mentioned, the ore was followed northwards along the Main Joint for 200 feet in the form of a pipe beneath the Upper 129 Toadstone. It then turned abruptly to the northwest as a downward slanting cavern about 20 feet in diameter and 400 feet long, lined with ore and calcite, and later swung around nearly to a westerly line. Here, in the 40-foot thick 129 Limestone, between two toadstones, occurred a large orebody different in shape and mineralization from any en-

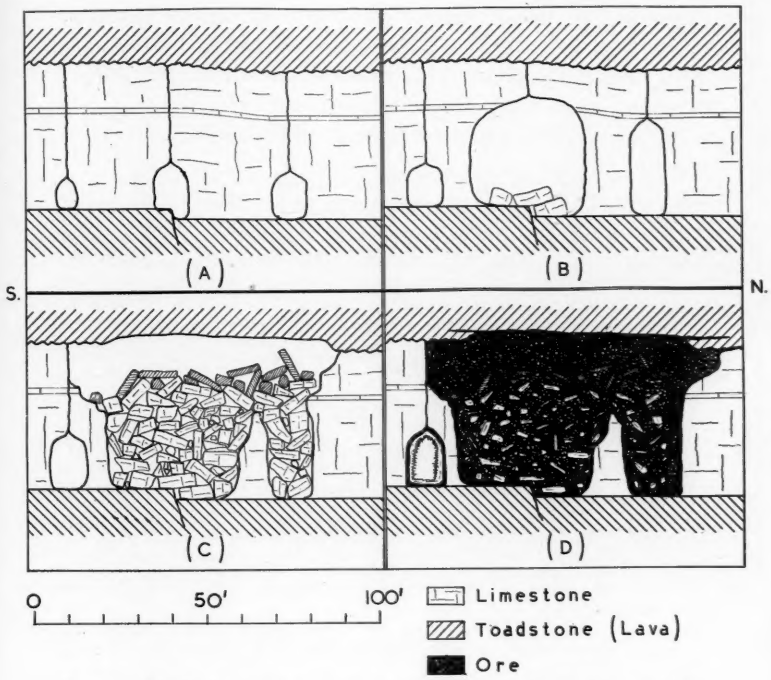

FIG. 9. Stages in the formation of the big orebody at the 129-fathom level.

(*A*) Cavernizing beginning along the joints.
(*B*) Caverns growing higher and wider.
(*C*) The roof collapses.
(*D*) The final orebody.

countered previously. As to its shape, the orebody was a typical manto, with a height of 40 feet and a width of 80 to 100 feet. The mineralization differed from that of higher horizons in that zinc predominated, whereas previously lead had been more important. Moreover, much of the ore was obviously a true metasomatic replacement instead of the customary cavity filling. Masses of fine-grained black sphalerite were encountered, very different from the usual brown variety. Blocks of partially replaced limestone were tumbled higgledy-piggledy, and masses of decomposed toadstone with ore minerals occupied the spaces between (Fig. 9). Most of the galena was concentrated along three parallel SE–NW lines, which seemed to represent the preexisting fissures along which the mineralizer travelled.

The history of this orebody seems to have been somewhat as follows:

(1) Folding along a NW–SE axis to produce the NW-striking joints in the limestone, with the axis of the fold pitching NW at a low angle.
(2) Cavernizing of the limestone on either side of these joints by the mineralizing solutions, confined to this horizon by the overlying and underlying toadstones, and arising from NW to SE (Fig. 9*A*).
(3) Cavernizing extending outwards from the joints, and upwards towards the roof, forming eventually an inclined cavern about 20 feet in diameter, similar to that found between the orebody and No. 2 Winze (Fig. 9*B*).
(4) Further cavernization upwards to the overlying toadstone would leave the latter unsupported, allowing masses of it to fall into the cavern along with blocks of limestone (Fig. 9*C*).
(5) The whole area would now resemble a large tunnel filled with fallen blocks, through which the mineralizing solutions could percolate as they ascended. Metasomatism of the limestone blocks would proceed apace; examples have been seen in all stages from unaltered limestone to masses that have been completely replaced by very fine fluorite and sphalerite.
(6) Rapid bleaching and decomposition of the fallen blocks of toadstone by the mineralizing solutions, forming a soft matrix for the galena.
(7) Finally, the crystallization in the remaining cavities of calcite and the brown variety of sphalerite, to form, with the galena, the usual type of cavity filling (Fig. 9*D*).

The orebody continued as described for about 400 feet, and then broke up into two or three parallel veins, still occupying the 40 feet of height between the Upper and Lower 129 Toadstones. The orebody has been followed to the far northwest end of the

mine, below the 144-fathom level where, though extensive, the ore has so far been poor in grade. The proper ore channel has not, perhaps, been followed, and is being sought for by current exploration work along the N-striking Pilhough Fault.

The 10-Foot Limestone.—Below the big orebody described above, a fair quantity of low-grade zinc ore has been mined in the thin limestone bed that lies between the Lower 129 Toadstone and the 144 Pump Station Toadstone. The ore, with its masses of calcite and coarsely crystalline sphalerite, seems to be a cavity-filling and not a metasomatic replacement. In one or two places it is connected by narrow fissures with the orebody above. It has not been followed as yet down the dip towards its source.

FAVORABLE AND UNFAVORABLE BEDS.

In lead-zinc replacement deposits in limestone the partiality or otherwise of the limestone to replacement is important, and seems to depend on such properties as composition and texture. Prescott's definition of a favorable bed is a characteristically practical one. He says:

> To avoid a long and intricate discussion of the physical or chemical properties and the exact factors that may render a bed favorable, such will be defined only as a bed in which ore occurs in unusual quantities, or one, identical in all characteristics, which, through some accident of location, was not subjected to mineralization.

On this basis, the favorable beds at Mill Close are the following:

(1) The massive, light-colored limestone underlying the cherty series in the First Limestone.
(2) The whole of the 84 Limestone.
(3) The uppermost 40 feet of the Second Main Limestone.
(4) The coarse-grained, light limestone near the middle of the Second Main Limestone.
(5) The 129 Limestone.
(6) The 10-Foot Limestone.

It is significant that all of these "favorable" beds consist of massive, light-colored, more or less coarse-grained limestones. The dark, thinly-bedded, cherty or shelly and coralline limestones are not as favorable as those noted above. This does not mean that no ore is found in the more impure limestones; all are capable of

replacement to a greater or less degree, but orebodies in the dark, thinly-bedded limestones tend to be small and irregular, except along fault fissures. The widespread development of branch orebodies between Nos. 1 and 2 Winzes would not have been possible without the presence of a thick bed of favorable limestone lying nearly flat and with toadstone above to act as a limiting bed.

Fletcher [14] stresses the importance of favorable beds. In the Mexican replacement deposits, a number of the best orebodies are found in dolomitic limestones, but it is Fletcher's belief that magnesian content is in no way an essential feature of a favorable horizon, and that the property of these beds that lent itself to magnesian replacement was the same one which later made them amenable to replacement by the mineralizer. It is their texture, and not the magnesian element of their composition, which was responsible for the mineralizer's invasion. The words he used to sum up the essential characteristics of a favorable bed might have been written about Mill Close. He says:

> Favorable horizons, where not dolomitic, are pure and reasonably thick. Thin beds and those high in silica, alumina, and carbon are unfavorable. In other words, where conditions at the time of deposition of the limestone fluctuated rapidly, resulting in thin and impure beds, they were unfavorable. Propitious horizons occur where conditions were only slowly changing over long periods of time and especially where they favored the building up of reefs now represented by thick members of the deposited series.

As will be seen from Table 2, the First Limestone has about 30 feet of dark bluish-grey to black cherty limestone, known locally as the "black beds," immediately underlying the shales. Below this the limestone is relatively pure, light colored and thickly bedded. On the line of the Mill Close Fault the ore persists up through the black beds to the base of the shale, and even, in places, up into the shale itself. On the southwest branch veins, which lie along joints and not faults, the ore generally stops short at the bottom of the black beds. Even the strong tendency of the mineralizing solutions to rise was unable to overcome the resistance of the cherty limestone to replacement. Stuckey [9] gives illustrations of these cases.

Below the middle of the Second Main Limestone there is a

pure, massive bed of crinoidal limestone that provides one of the most striking local examples of favorability to replacement, at the 112-fathom level, just north of No. 2 Winze (Fig. 8, point "A"). In the crinoidal limestone the orebody attains a width of 17 feet, and in the overlying dark limestone the width is abruptly contracted to a bare 4 feet.

Table 3 gives the analyses of a number of typical limestone specimens, from various horizons throughout the series. The

TABLE 3.

ANALYSES OF LIMESTONE SAMPLES.

No.	H_2O	SiO_2	Fe_2O_3 +FeO	Al_2O_3	CaO	MgO	$(Na, K)_2O$	MnO	F	CO_2*
1	0.08	2.82	0.15	1.05	52.82	0.59	0.21	0.50	0.20	41.4
2	0.08	11.16	2.50	0.46	47.63	0.23	0.84	0.24	Nil	36.5
3	0.06	4.66	0.22	1.52	51.62	0.76	0.37	0.28	Nil	40.3
4	0.02	1.36	0.31	0.13	54.48	0.61	0.10	0.03	Nil	42.9
5	0.09	0.50	0.20	0.13	54.70	0.57	Tr.	0.19	0.05	43.3
6	0.03	0.54	0.11	0.28	54.60	0.62	Tr.	0.06	0.02	43.4
7	0.02	0.40	0.05	0.08	55.01	0.45	Tr.	0.15	0.03	43.4

* CO_2 accurate to about 0.5 per cent.

DETAILS OF SAMPLES.

No.	Taken from	Position in Series	Description	Favorable (F) or Unfavorable (U)
1	248′ down Lees Shaft	At bottom of "black beds"	Fine-grained, hard, brown limestone.	U
2	440′ down Lees Shaft	1′ below Upper Toadstone	Hard, siliceous, grey, marmorised limestone.	U
3	63′ down No. 1 Winze	1′ above Intermediate Tuff	Light-colored, siliceous, shelly limestone.	U
4	87½′ down No. 1 Winze	24′ below top of 84 Limestone	Coarse-grained, nearly white limestone.	F
5	105′ down No. 1 Winze	4′ below top of Second Main Limestone	Fine-grained, light brown limestone.	F
6	117′ down No. 1 Winze	16′ below top of Second Main Limestone	Fine-grained, light brown limestone.	F
7	172′ down No. 1 Winze	71′ below top of Second Main Limestone	Fine-grained, dark brown limestone.	U

purity of the favorable limestones is notable, but one of the samples marked "unfavorable" (No. 7) is even purer, from which it would seem that color and texture provide a better guide to favorability than does composition.

MINERALIZATION.

Primary Minerals.—The principal primary minerals are galena, sphalerite, pyrite, calcite, fluorite, and barite. The galena occurs as crystals or masses in a calcite gangue, mostly in the form of a continuous rib, but rarely disseminated in small (⅛") cubes in the calcite. The proportion of silver in the galena is very low, only 1 to 1½ ounces per ton.

Sphalerite has a wide distribution, persisting along joints for a long distance beyond where the galena content ceases to be payable. In the First Limestone, sphalerite [3] was the earliest ore mineral, succeeded by fluorspar, galena, barite, calcite and pyrite. Lower down, most places undoubtedly show sphalerite as being later than the galena. The customary order is calcite, galena, calcite, blende, calcite. Fig. 11 is a cross-section of a typical small pipe in which the order of deposition is difficult to determine. In general, there seem to be two ages of sphalerite in the mine, one older and one younger than the galena. Certainly, there are two varieties of the mineral, one (the later) occurring as a band of large honey-colored to brown crystals in a calcite gangue, the other (the earlier) as a fine-grained, black, metasomatic replacement of fluoritized limestone. The fine-grained "black jack" has only been found in the big 129-fathom level orebody. The sphalerite of the 10-Foot Limestone below resembles the first type in its occurrence along with calcite as a cavity filling, but its color is black, like the 129 level type. These differences may be due to variations of temperature, but there is room for investigation here. Even the brown crystals have streaks of black in them, and both types under the microscope are seen to contain numbers of minute specks of chalcopyrite (?) averaging 1/10 mm. diameter or less. Both types of sphalerite are exceptionally pure,[6] averaging about

[6] Indications to date are that the brown variety is somewhat purer than the black, as might be expected, but the difference is not great.

65 per cent Zn along with a valuable 1 per cent Cd. Only at the 129-fathom level is there any intermixing of galena and sphalerite (as in Fig. 10) and a high-grade flotation concentrate is made from the ore without difficulty.

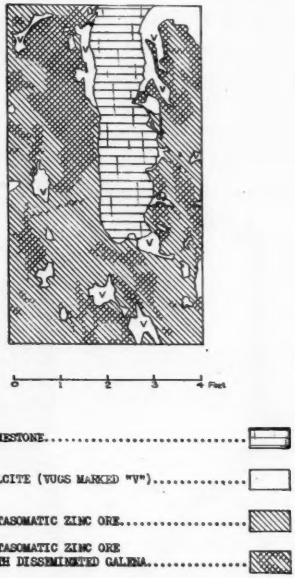

FIG. 10. 129-fathom level. A fallen block of limestone surrounded by ore of the metasomatic replacement type.

Pyrite, fluorite, and barite were evidently more plentiful at higher levels than they have been in recent years. Pyrite, where found, generally occurs as narrow veinlets in areas containing little or no lead ore. Parsons mentions a rib of pyrite nearly a foot thick as commonly occupying the center of a banded vein, but this feature was missing in Stuckey's time. Cubes of pyrite are common in many of the toadstones, within a few feet of the upper and lower contacts. Marcasite occurs as a fine dust-like film on the surface of, and in layers inside, crystals of fluorite

and calcite. Fluorite crystals, speckled with marcasite, were common in the First Limestone. In the lower limestones crystalline fluorite is rare, except near the extremities of branch orebodies, where it is usually associated with sphalerite and greenockite. A dark band, an inch or so in width, commonly seen in the limestone adjacent to the ore, and formerly assumed to be due to silicification, has been found to be caused by fluoritization. Barite is

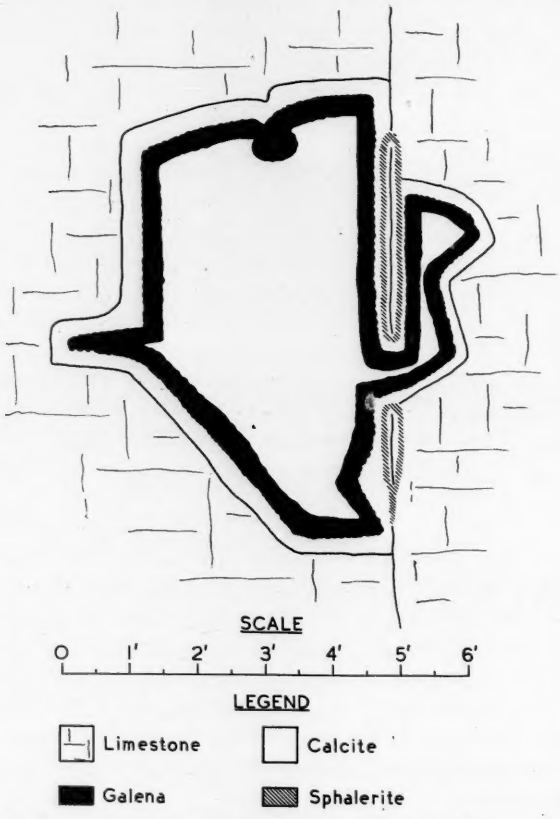

FIG. 11. Cross section of a small pipe, 93-fathom level (N 5190, W 370)

never seen at the lower levels, but was fairly common in the older parts of the mine, where it occurred in bands of pinkish "caulk" or as white crystals of cockscomb spar.

Calcite is the almost universal gangue mineral, occurring as white masses, and as large "dog-tooth" crystals lining every cavity. Twinned crystals, including the so-called Mill Close twin, characterized by its re-entrant angles, are common.

Secondary Minerals.—Calamine (called hemimorphite in Britain), $(ZnOH)_2SiO_3$, is the commonest secondary mineral, and one of the last to have been deposited. It occurs as a thin superficial coating of small crystals on the faces of calcite crystals. Some beautiful platy specimens have been formed by the subsequent solution of the calcite.

Cerussite is fairly common throughout the mine, in the form of small colorless tabular crystals, commonly twinned, scattered over the surface of massive galena. The crystals rarely exceed ⅛ inch in size.

Greenockite, CdS, occurs as a bright yellow incrustation on the surface of other minerals, and in cracks in them, where sphalerite has been undergoing alteration. The crystalline variety has not been found at Mill Close.

Dundasite, hydrozincite, and aurichalcite are secondary minerals of rare occurrence, that have been noticed at various times. There is a possibility that some of the zinc sulphide is the secondary, hexagonal form, wurtzite, but this remains to be proved.

A notable feature about the secondary minerals is their occurrence at the lowest levels of the mine, 1,200 feet below the surface, and 500 feet below sea level. In other words, the Mill Close manto is, for all its length, still in the zone of oxidation.

WATER.

In any low-lying mine in limestone, such as Mill Close, water will always be an important factor. The quantity pumped at Mill Close has risen from 1,000 imperial gallons per minute in 1887 to 1,600 in 1920; 2,000 in 1929; 2,350 in 1932; 4,300 in 1937; and 5,550 in 1938.

Apart from the high cost of dealing with so much water at all times, the possibility of closing down temporarily during periods of low metal prices is ruled out.

There are a few compensating advantages, however. As regards power, the big pumping load makes for a high load factor. The temperature gradient, because of the water, is low. But the greatest value of the water is the way it can be used to aid development. A new flow in one place coincident with a cessation of flow somewhere else indicates a connection. Deductions can be made from the distinctive analyses and temperatures of water from different sources. In ore-bearing ground, it is usually wise to seek the source of the water, because it follows the most open channel available, and so would the mineralizing solutions have done, as a general rule.

It should be noted, however, that not every water-bearing fissure is worthy of exploration. Every open fissure in the limestone will contain water, but not all contain ore. Much fruitless exploration work would be avoided if this axiom were more generally realised.

In February, 1938, a fault (since named the Pilhough Fault) was encountered in driving west on the 144-fathom level. The tremendous inflow of silt and water that followed was too great for the pumping plant at that level, with the result that the water rose almost to the 103-fathom level before it could be checked, and more than a month was needed to dewater the workings. The permanent increase to the inflow was 1,000 gallons per minute.

The toadstones seal off the limestone into watertight layers, except where the toadstones die out or where open fault fissures give access from one layer to the next. The result is a series of perched water tables—each lying on top of a toadstone—above the main water table. The flooding of a year ago was the result of letting in the water from one of these perched water tables, from which the workings had previously been protected by the overlying toadstone.

South and west of the mine the limestone surface reaches an

elevation 900 feet or so above the level of the River Derwent, which controls the ground water level. This circumstance, along with the alternation of permeable and impermeable layers, and the presence, near the river, of open fault fissures, gives the conditions necessary for artesian circulation. This is put forward as a possible explanation of the extreme depth of the oxidized zone, and may even explain the original cavernization.

SOURCE OF THE ORES.

The author finds himself in agreement with Wedd and Drabble's conclusion "that local circumstances in Derbyshire agree best with the hypothesis of deposition, in fissures and to a small extent as a metasomatic replacement of the country rock, from a heated aqueous solution containing gases and forced up from a great depth, possibly in connection with the later phase of igneous activity." It has not been possible to determine the temperature of the mineralizer by microscopic methods, but unaltered coal seams indicate that the temperature was comparatively low.

The rising course followed by the ores has been stressed, and it has been shown how the ascensive force was never in abeyance, even the flatter parts of the deposit having a slight rise from the source towards the outcrop. In this connection two further points might be mentioned. The first is that wherever the overlying limiting bed (toadstone, wayboard, or shale) had such a low dip that it permitted only a very slight ascent for the mineralizer, the horizontal spread was considerable. Areas of large horizontal spread are: No. 2 Winze to No. 1 Winze, No. 1 Winze to Ventilation Shaft, and Lees Shaft to 750 feet south of Warrencarr. From the longitudinal section (Fig. 3) it can be seen that these are areas where the dip of the overlying beds is low. The second point is that, in the flatter-lying parts of the deposit, the bottom of the ore in the narrow rake-joints always rises on a slope that is steeper than the slope of the ore in the main joint adjoining.

Present development, at the far northwest end of the mine, is exploring the Pilhough Fault, the potential importance of which

takes three possible forms, namely: (1) As a channel for ascending ore-solutions leading to the known orebodies nearby. A fault which cuts deep is the most likely channel of entry for the mineralizing solutions; (2) As a possible lateral connection between the known orebodies and a source farther north; (3) As a channel leading upwards—possibly to the base of the shales—to another manto deposit like Mill Close, which might lead to the rich but shallow mines of Alport, a mile to the west.

GEOLOGICAL MAPPING.

The routine geological work, from the sectioning of main shafts and winzes, and of intermediate rises and winzes, to the detailed study of the intervening drives, is almost identical with the method used at El Potosi Mine, Chihuahua, Mexico [16], and need not be described here. The present writer's proposed paper will include a complete series of vertical sections, for anyone interested in the local stratigraphy.

ACKNOWLEDGMENTS.

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ASSISTANT MANAGER,
MILL CLOSE MINES, LTD.,
DARLEY DALE, DERBYSHIRE, ENGLAND,
April 14, 1939.

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METASOMATISM ASSOCIATED WITH TERTIARY MINERALIZATION IN NEW GUINEA.

N. H. FISHER.

ABSTRACT.

The alteration of the country rocks that is associated with the Tertiary mineralization in the Wau-Edie Creek area, New Guinea's principal gold-mining district, possesses certain peculiar features. The porphyries and phyllites of the district have been more or less uniformly altered over a considerable area, corresponding closely to the limits within which the small quartz-gold stringers occur, whence have been derived the rich alluvials of Edie Creek and the adjacent streams. The larger lodes of the district are directly accompanied by only comparatively slight metasomatic effects. An outline is given of the geology of the area, and a brief description of the four principal types of lodes, after which the general and the local metasomatism are described.

OUTLINE OF THE GEOLOGY OF THE WAU-EDIE CREEK AREA.

THIS paper deals only with the comparatively small area around Edie Creek and Wau, in the heart of the Morobe Goldfield, for although mineralization and workable gold deposits, some of them probably of Tertiary origin, occur in other districts of the Mandated Territory, there has been practically no exploitation of gold-bearing lodes outside the Wau-Edie Creek area, certainly none on the mainland of New Guinea.[1] In order to understand properly any reference to the lodes, it is necessary first to give a brief outline of the general geology of the area.

The basement rocks of the Morobe District are slates, schists, and phyllites, with some lenses of limestone, referred to as the Kaindi Series, after Mt. Kaindi, which lies between Wau and Edie Creek. This basement complex extends throughout most of the Mandated Territory, and forms the foundation upon which

[1] No reference is being made to Papua, because no information bearing on the subject of metasomatism associated with the lodes there is available, although Tertiary mineralization of a type similar to that found on the Morobe Goldfield is known to exist, particularly on Misima Island.

the later sediments, mostly of the Tertiary age, have been laid down. Its age is not known definitely, but it is intruded by pre-Tertiary granites and granodiorites, and was already folded and

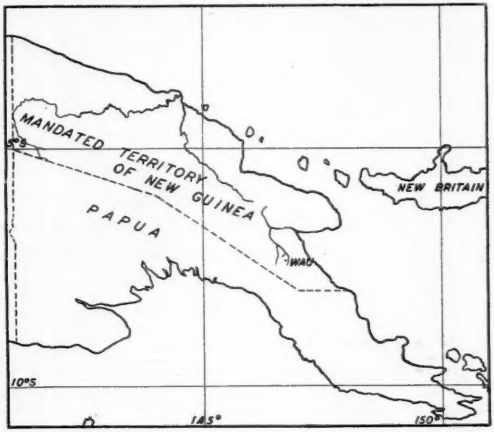

FIG. 1. Locality plan showing approximate position of Wau and Edie Creek.

altered when these intrusions took place, so that it is safe to say that it is at least pre-Mesozoic. In the principal gold-bearing area around Edie Creek, the phyllite of the Kaindi Series has been altered by hydrothermal solutions to a chloritoid schist, locally known as mudstone, because of the appearance of the weathered product.

A granodiorite batholith occupies a large area of the Morobe Goldfield, but although it outcrops within a mile or so of some of the Tertiary lodes, its influence on them is negligible and its presence of no importance to this discussion. This granodiorite has certainly introduced a considerable quantity of gold, apparently mainly in small leaders, and the gold of Sandy Creek, Poverty Creek, Black Cat Creek and Bitoi River, and most of that of the Upper and Lower Watut River is derived from this source, but this mineralization has not extended into the central area with which this paper is concerned.

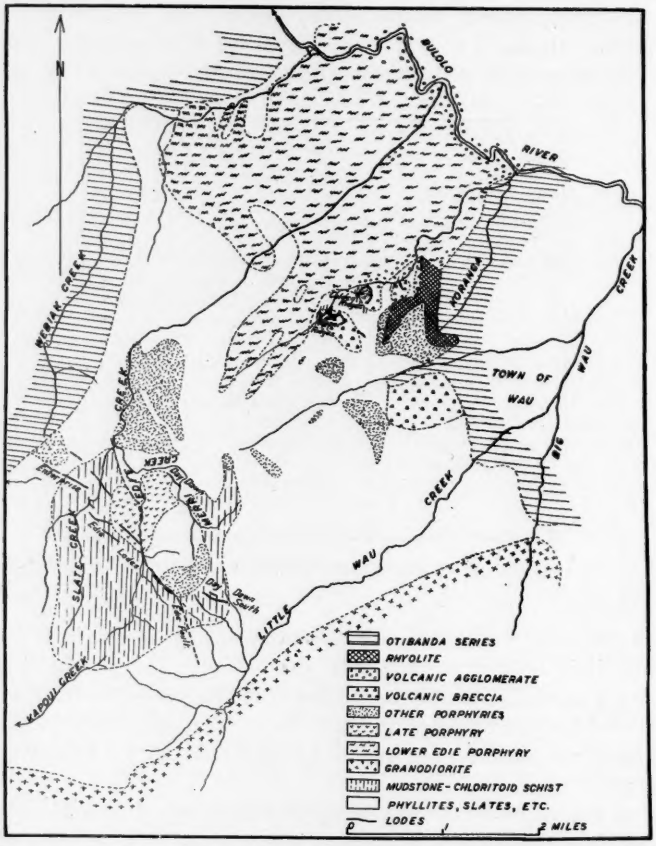

FIG. 2. Geological Sketch Plan of the Wau-Edie Creek Area, Morobe Goldfield, Mandated Territory of New Guinea.

The distinctive feature of the Wau-Edie Creek area is the presence of a series of intrusions of Tertiary porphyries. As they are essentially independent of each other, it is difficult to establish their sequence in detail, but at least three definite ages are known. The earliest is the Lower Edie porphyry, a fresh, fairly coarse-

grained, quartz-biotite porphyry, outcropping over an area of several square miles to the immediate north and west of the principal mineralized centers. Later than it are a number of quartz-, biotite-, hornblende-, and feldspar-porphyries, not necessarily contemporaneous, which are distributed over most of the Edie Creek area. The latest intrusions are also quartz-biotite porphyries, but before their appearance violent volcanic activity had taken place, producing thicknesses of many hundreds of feet of volcanic breccia, composed of angular and sub-angular fragments of slate and the earlier porphyries, and the latest porphyries are intrusive into these breccia masses.

Many of the porphyry intrusions cannot be definitely placed with regard to the two later categories, particularly where only weathered outcrops are available. In many places the constituent fragments of the breccia, and the fact that some of the porphyries intrude the breccia, afford the only reliable criteria for relative age determination; many of the porphyritic intrusions are isolated from the breccia areas.

After the last porphyry intrusions, a further stage of volcanic activity occurred, with a source apparently situated within the Lower Edie biotite-porphyry, for its products are a series of tuffs and agglomerates composed mainly of fragments of the biotite porphyry. About this time, probably in the Pleistocene period, the basin that forms the present valleys of the Bulolo and Watut Rivers became dammed up, and the deposition commenced of a thick series of freshwater sediments, conglomerates, shales and sandstones, with interbedded tuffs and even, in places, flows of obsidian and rhyolite, and volcanic breccias. Movements that initiated the draining of this lake were also probably responsible for the gentle folding exhibited by the lacustrine beds. These must be exceedingly recent, as bones found embedded in the sediments near Otibanda on the Watut River have been established as belonging to a species of Nototherium similar to those found in the Pleistocene and recent swamps of South Australia. Following the drainage of the lake, the gently sloping areas at the base of Kaindi mountain were covered with a mass of unsorted boulder

beds swept from the mountains by the rejuvenated streams, and between Wau and Golden Ridges flows of rhyolite breccia, much of it now opalized, were extruded over a limited area.

THE LODES.

Edie Creek Stringers.—It is estimated that up to the end of 1938 about 1,000,000 fine ounces of gold have been produced from alluvials originally derived from near the head of Edie Creek. This includes the gold won in the Edie itself and also that taken out by the dredges and other operations on the Bulolo and Watut rivers below the mouth of Edie Creek, where the percentage of Edie gold at any place can be calculated from the fineness, the admixed gold from other sources, chiefly granitic, being of a much higher grade. As only a comparatively small proportion of the Bulolo flats has yet been dredged the total amount of gold derived from the Upper Edie area must be exceedingly large. Little doubt exists that practically the whole of this gold is derived from a series of small, rich, quartz-gold stringers scattered throughout a certain limited and fairly well-defined area at the head of Edie Creek. These stringers are seldom more than an inch thick or a few yards in length, but contain a high percentage of gold. In the specimen stone, which is of very common occurrence in Edie Creek, the two walls of the vein from which it was derived can often be seen. The larger specimens are mostly flat, and the gold forms an interlacing network with quartz between the walls. In general, these rich stringers are found only by accident in the course of alluvial working, and except in one instance where a stringer larger than usual was traced for its full extent, are not worked for gold and are important only as the source of the alluvials. The extreme richness of the alluvials in the Upper Edie area is due to the softness of the mudstone and altered porphyries that comprise nearly all of the watershed, and to the presence of a hard bar of silicified slate at the head of the Lower Edie gorge. The soft rocks above after weathering have been removed as mud in suspension, leaving only the quartz, a few boulders of the harder portions of the porphyry and slate, and the gold, in the

gravels above the bar, where the streams soon wore down to a comparatively flat grade, in violent contrast to the series of gorges below the hard bar.

Edie Lodes.—The group of orebodies referred to under this heading occur along a NW–SE line of fissuring, immediately to the south of the main intrusive body of porphyry at Edie Creek, which is assumed to be more or less contemporaneous with the later porphyries at Golden Ridges. A large pre-ore fault, known as the Edie fault, cuts obliquely across the general direction of the lodes, and the lodes themselves occupy zones of fissuring, and are cut by a series of faults that are considered to have originated earlier than the ore, though post-ore movement has undoubtedly taken place along them. This group of lodes includes Edie No. 1, No. 2, No. 3, No. 4, No. 5, Karuka lode, Slate King, and Surman's vein on New Guinea Goldfields' property, the Enterprise or "Developments" lode at the northwestern end, and Day Dawn South at the extreme southeast. Edie No. 1 lode lies within the biotite-porphyry, the remainder are in the mudstone, although closely associated with either the main porphyry or smaller lenses. All these lodes are similar in disposition, origin and mineral composition, although of course local variations are found. They are generally three to four feet wide, but widths up to 15 feet or even more occur, notably in the Karuka and Enterprise lodes. The dip varies from 30° to 90° and is generally towards the southwest. The oxidized lode material is soft, and consists mainly of manganese oxides and quartz, commonly well laminated, with alternating layers of varying thickness of fine sugary quartz, crystalline quartz, and the manganiferous oxides. In the unoxidized zone, the lodes where exposed are solid calcite and quartz with a little rhodocrosite. Pyrite, sphalerite, galena, stephanite, chalcopyrite and tetrahedrite have also been identified. Gold values are high near the surface, 10 to 20 dwts. or more per ton, except the wider lodes, which run 5 to 12 dwts., with richer patches. Values decrease in depth and little ore of the sulphide zone has yet been found to be payable. Silver values are very high in the oxidized material, in places up to 100 oz. or more to

the ton, but decrease rapidly with depth. The silver is not amenable to treatment, less than 30 per cent being extracted by combined amalgamation and cyandation, and it is considered to be present mostly in the form of a refractory silver manganite, insoluble in acids or cyanide. Secondary enrichment seems to be largely, though not entirely, responsible for the distribution of both the gold and silver values, more especially the silver.

Day Dawn Lode.—Although in many respects similar to the Edie lode the Day Dawn orebody differs sufficiently to be described separately. It lies immediately to the north of the main porphyry mass and out of the general line of shearing occupied by the other lodes. The lode is mainly contained within the Kaindi phyllite, which is here comparatively unaltered, no mudstone being developed in the immediate vicinity. The southwestern end of the lode occupies the contact of the porphyry and the phyllite. The lode material is mostly small quartz stringers in schist along a fissure zone, which makes out from the porphyry-phyllite contact, first cutting obliquely across the strike and dip of the phyllite, but later turning to conform with it. Manganese oxides are present as in the Edie lodes but it is highly manganiferous only close to and along the porphyry contact. In dip and strike it resembles the larger group, *i.e.,* NW strike and dip 40° to 70° SW. The average width is three to four feet. Secondary enrichment, high and intractable silver values decreasing rapidly in depth, and low grade primary ore are further features in common.

Day Dawn Lode near the surface was the richest on the field, very rich specimen ore being plentiful near the outcrop, and generally a high grade of ore, averaging over 1 oz. Au per ton. This decreased to 5 dwts. in the lowest adit, the No. 2 level, 310 feet below the outcrop, and on this level operations and exploration both ceased. Silver has been leached from near the surface, although the values are still high, but not nearly so high as 100 feet or so lower down. Higher silver content is also noticeable in the manganiferous portion near the porphyry contact. Primary ore on the No. 2 level carries a fairly constant 2 ozs. of silver per ton

with little correspondence to the gold content. The Day Dawn Mine produced about 21,000 ozs. of gold from 54,000 tons of ore. The fineness of the gold as it occurs in the mine is similar to that of the Edie lodes and of the rich quartz-gold stringers that furnish the gold of the alluvials, namely, 490 to 540, the fineness decreasing with depth from the surface.

Golden Ridges Area.—The lodes in this section, two to three miles northeast of Edie Creek, are quite distinctive in character and associations from any of the Edie lodes, although points of resemblance do exist. They are generally flat-lying or gently dipping bodies of calcite, quartz and manganese minerals, up to 25 feet or even more in thickness, and are contained within the volcanic breccia to which reference has previously been made. In most cases the orebodies are overlain by flat sills of porphyry intrusive into the breccia. Near the surface the lodes consist mainly of soft manganiferous material carrying good values, as at Golden Ridges itself, where 150,000 tons of ore averaging over 1 oz. per ton were found lying flat, almost on the surface. At no great depth they pass into solid calcite, with varying proportions of quartz, rhodocrosite and pyrite, though partial oxidation of the pyrite persists in streaks for some distance down the dip. The best values are associated with the oxidized manganese, or with pyrite in quartz. Secondary enrichment, partly chemical but mainly mechanical, has played a small part in the arrangement of values within the lodes. Silver values are not high, commonly not more than twice the gold content, although somewhat higher in the thoroughly oxidized portions. Fineness of the gold is just under 600 parts per 1000. Ore formation has been principally by replacement of the breccia, but the presence of gouge on both walls of some of the lodes suggests that previous fissuring guided the ore-bearing solutions. The genesis of the lodes is considered to lie in the parent magma of the porphyry that intrudes the breccia and overlies the lodes. The Lower Edie porphyry mass close by is much earlier than the ore.

Of the lodes of the Upper Ridges area, three of the largest, Upper Ridges, Golden Ridges, and Golden Peaks, form a group

which, from their similar disposition and their occurrence at intervals down the mountainside, suggest that they may be step-faulted portions of the same original lode. Although the mineral constitution of the various sections does not entirely confirm this view, sufficient detailed fieldwork has not yet been done to disprove it or otherwise. All of these lodes, as well as a lower lode at Upper Ridges, and the more steeply dipping Creek Vein and Upper Ridges South orebody, do not, as far as is known, persist into the schist bedrock that underlies the breccia. The one exception to this rule is Anderson's Creek lode, which is a steeply-dipping calcite orebody, 12 to 15 feet thick, contained almost entirely within the schist at the eastern end of and underneath the breccia. Breccia forms the hanging-wall of the lode for some distance, but mainly beyond the limit of values. The lode is largely a fissure vein, parallel to the strike of the schist, but cutting across the general dip, which, however, is overturned near the lode to conform with it. Secondary enrichment has played a rather larger part in the distribution of values near the surface as might be expected from its general features. Otherwise the Anderson's Creek Lode is closely similar to the other orebodies of the Golden Ridges area and probably derived from the same magmatic source.

GENERAL METASOMATISM.

The metasomatism associated with the lodes of the Wau-Edie Creek area is best dealt with under two headings, the more general metasomatism previously mentioned, which has converted the phyllite into mudstone, and the local metasomatism directly associated with the ore-bearing solutions, which has affected the wall-rock in the immediate vicinity of the lodes. The general metasomatism is remarkable for its close correspondence with the Tertiary gold-bearing areas, and, although only a general indication, is far the more important from the point of view of ore-finding. Its most prominent effects are the transformation of the phyllite of the Kaindi Series into a soft chloritoid schist, and the quartz-biotite porphyry into an alteration product in which all of the constituent minerals except the quartz have been greatly

affected. The unaltered phyllite consists mainly of quartz granules showing wavy extinction, and scales of micaceous minerals, chiefly biotite, with a well-marked sub-parallel arrangement. A few large plagioclase crystals, acid andesine in composition, are present, and flakes of pale-colored chlorite accompany most of the biotite. Accessory minerals are titanite, magnetite, ilmenite, leucoxene and rutile. The chloritoid schist to which the phyllite has been altered shows much similarity in thin section to the parent rock. Granules of quartz are the most conspicuous constituent, and are mixed with sheaf-like aggregates of chloritoid prisms and anauxite, an alteration product of biotite. Plagioclase is somewhat altered and biotite flakes are mostly distorted. Some chloritization has taken place, and grains of iron-poor epidote are not uncommon. Much of the original structure of the phyllite is obliterated, and the chloritoid needles are generally orientated at random.

The most striking difference between the original rock and the chloritoid schist is in the appearance of their weathered products. The phyllite breaks down in the normal manner of surface weathering to a greater or less degree, and in the beds of the creek remains quite unaltered, but the chloritoid schist, for 200 feet or more from the surface, depending on the topography, weathers completely to a rock that is best described by the local name given to it—" mudstone "—and which looks at first glance like a weathered tuff. The original schistose laminations and in places contortions are preserved, however, although the rock down to the unoxidized zone is invariably soft enough to be picked readily by hand. The outcrops of veins in this rock behave in a most peculiar manner, owing to its very plastic nature, and hill-creep may carry the vein downhill or overturn the dip and generally dislocate the outcrops of a lode that is otherwise quite continuous underground.

The alteration of the porphyry is even more pronounced in thin section, although not quite so obvious in the hand specimen. All the intrusions associated with the mineralization both at Edie Creek and Golden Ridges were originally quartz-biotite porphyries

with a little hornblende and abundant plagioclase feldspar, mostly acid andesine. They have been altered along similar lines to the phyllite, the differences reflecting divergences in the mineral composition of the original rocks. The clear quartz grains alone are unchanged. Biotite is completely altered to anauxite, $Al_2O_3.3SiO_2.2H_2O$. The original determination of anauxite in these rocks was made by J. D. H. Donnay [2] in an examination of a parcel of specimens from New Guinea Goldfields Ltd. and has since been confirmed in several thin sections. It is silvery-white, pseudomorphous after biotite, and Donnay considers that it was probably developed by way of an intermediate chlorite stage. The feldspars of the porphyry are entirely converted to sericite, though traces of the polysynthetic twinning lamellæ remain. Hornblende is completely altered and specks of leucoxene are prominent around the boundaries of the former crystals and also within them. The groundmass is very fine grained and composed largely of quartz and altered feldspar with rutile, secondary titanite, pyrite and magnetite. Donnay considers, no doubt quite rightly, that the alteration of the mudstone and the porphyry is due to the action of hydrothermal solutions at low temperatures, carrying the end products of volcanic emanations, chiefly carbon dioxide. The principal results of the alteration are the anauxitization of the biotite, the complete sericitization of the feldspars, the formation of chloritoid, and the leaching of the metals out of the rocks in the form of carbonates and bicarbonates. The differences in the effect on the phyllite and on the porphyry are to be expected from their different chemical composition. Donnay remarks "comparison of the formulæ of anauxite ($Al_2O_3.3SiO_2.2H_2O$) and chloritoid ($Al_2O_3.FeO.SiO_2.H_2O$) shows that the latter will be produced in a case of deficiency of silica and water and where the removal of iron is not complete. Reasons why chloritoid should develop in the phyllite more easily than anauxite must be sought for in, (1) the small amount of silica available for transformation in the original rock—as compared with the porphyry, and (2) the difficulty for hydrothermal

[2] Donnay, J. D. H.: Private report to New Guinea Goldfields Ltd. on a parcel of rock specimens from their properties.

solutions to circulate through a finegrained compact metamorphic rock."

The source of the volcanic emanations lies doubtless in the later stages of the vulcanism of which the porphyries are a phase and which also produced the volcanic breccias of the Golden Ridges area. The alteration obviously preceded mineralization, for in porphyry adjacent to the lodes, pyrite crystals are found replacing anauxite and the sericitized feldspars, and near the Day Dawn lode calcite also is found replacing the altered feldspar of the porphyry. The exact connection between this general metasomatism and the mineralization is not entirely clear, but its close spatial correspondence with the gold-bearing area suggests that it is most intimately associated with the mineralization that produced the Edie Creek stringers. Apparently both originated within the same magmatic source and used the same channels of access to the surface and near-surface rocks. The plan (Fig. 1) shows exactly how all the areas that shed gold—derived almost entirely from the small rich stringers of the Edie Creek area—lie within the mudstone belt. The whole of Edie Creek itself above the Merri junction drains mudstone or altered porphyry, with the Midas, the richest portion of the field, situated fairly centrally. Slate Creek on the west is only partly in mudstone and carries a proportion of higher grade gold from an earlier source situated near the head of the creek. Merri Creek has derived most of its gold from near the head on the east side and from a series of adjacent tributaries, while the central stream, which drains an isolated "inlier" of comparatively unaltered phyllite, has been named "Mystery Creek" by the disappointed miners because of its barrenness. Outside the divide of the Edie shed the mudstone extends into the heads of Little Wau Creek near Day Dawn South. These streams have been worked for gold and the payable section of the main creek near Wau itself, below the series of gorges that occupy the central portion of the creek, has also derived its gold from the top mudstone belt. To the south a small quantity of alluvial gold identical in fineness and character with the Edie gold has been won from Kapoul Creek which drains the

fringes of the mudstone, where it passes into unaffected phyllite. Similarly, a very small amount of gold in Oriabanda Creek has come from the western edge of the metasomatized area behind Enterprise Mine.

As previously mentioned, nearly all of the alluvial gold is undoubtedly derived from the small rich quartz-gold stringers, mainly in mudstone, but also in the altered porphyry, and in addition all the larger lodes of the Edie group are found within the same rocks. Day Dawn lode is a partial exception in that the phyllite that comprises most of the wall rock is practically unaltered, but the porphyry at the northwest end of the lode has been affected by the alteration quite as much as that adjoining the Edie lodes.

The same type of metasomatism is present in the later porphyries of the Golden Ridges area, but " mudstone " is developed to a very limited extent in the phyllite only where it closely approaches the orebodies, which are mostly contained within the breccia. Just at a few isolated localities where the lode abuts on to the old bedrock, the mudstone alteration is locally prominent. The porphyries overlying the orebodies, however, show an intense degree of alteration, the feldspars are completely sericitized and partly converted into kaolin, the original biotite crystals altered to anauxite, which has in some cases given way partly to kaolin and has been replaced by calcite and pyrite, the pyrite in places forming a thin border around the former biotite crystals. Within the breccia the contained pebbles of the earlier Lower Edie porphyry have suffered similarly in the vicinity of the lode, but the schist fragments have as a rule been affected only slightly. As far as mining has proceeded up to the present, the breccia is mostly soft and it is exceedingly difficult to make thin sections, and comparatively little suitable material has been recovered from the drill cores. It is quite definite, however, that the same general metasomatism has affected the rocks of the Golden Ridges area near the lodes—with the one exception of Anderson's Creek where it is displayed to only a very slight extent—as the Upper Edie area. It is also certain that the extent of this alteration is much

less in the lower than in the upper area, but on the other hand, the total amount of gold introduced in the Upper Edie area is vastly more than that around Golden Ridges, so that a rough proportion exists between the total quantity of alteration and the total gold introduced.

It is quite obvious how valuable a guide to prospecting this special type of alteration is, for wherever it is present, either in porphyry, phyllite, or breccia, lodes have been found or alluvial gold has been shed, whereas no late Tertiary sources of gold entirely removed from these areas are known. So, although it is rare that conditions allow the presence of the alteration to be a close direct guide to ore, it apparently delimits the areas in which prospecting is liable to prove profitable, at least, in regard to lodes of this latest epoch of mineralization.

LOCAL METASOMATISM.

On this subject there is disappointingly little to say. The Geological Survey of New Guinea is as yet in its infancy and no chemical analyses of the rocks either near to or distant from the veins have been made, though excellent opportunities exist to make a detailed study of the chemical changes in both the porphyries and the mudstone in the Edie mines along the crosscuts as the lodes are approached, and it is hoped that it will be possible in the near future to do some work on this problem. With regard to the lodes of Edie group, H. M. Kingsbury,[3] who was chief geologist to New Guinea Goldfields Ltd., for many years, during most of their exploration and development work, states that the country rock close to the principal veins shows no apparent alteration or difference to the rock far away, and that in exploratory crosscuts the veins are encountered abruptly with nothing to indicate their presence even within a few inches of the ore. In a few places incipient silicification, slight chloritization, and weak pyrite dissemination were seen but they were exceptional instances. At Day Dawn South the presence of silicification on the footwall was almost invariably associated with poor values in the lode itself.

[3] Kingsbury, H. M.: Report to New Guinea Goldfields Ltd.

The Day Dawn lode is less well defined, mineralization in places making out for a short distance along cracks and fissures and even bedding planes in the country rock. Strong silicification is present in localized patches, and pyrite is abundant near the lode, especially in the porphyry, which also as a rule shows evidence of replacement of some of its minerals by calcite. Epidote and a little chlorite are also present in the porphyry, and the sericitization of the feldspar may be carried through to kaolin, but this is probably more a secondary than a primary effect. It is difficult in the case of the porphyry near the Day Dawn lode to distinguish between the effects of the general hydrothermal alteration and the local metasomatism that was more closely associated with the ore deposition.

In the Golden Ridges area where the country rock of the lodes is mostly breccia, the same difficulty occurs to some extent. The most noticeable metasomatic effect is a strong pyrite dissemination through the breccia adjoining the lode, which shows up exceedingly well towards the base of the oxidized zone as a strong brown iron staining for a few feet on either side, in places carrying low gold values. This staining is a quite useful indication of the presence of the wall of the lode, which is difficult to follow in a drive on account of the flat dip, small variations in dip throwing the lode many feet out of position on a horizontal plane. In the drill cores, veinlets of calcite become increasingly more frequent as the lode is approached, but this is hardly to be described as a metasomatic effect. The same condition exists at Anderson's Creek, where one of the drives closely follows the bottom of the breccia where it rests upon the phyllite and the whole is thoroughly impregnated with calcitic mineralization of an irregular nature, in cracks, blobs and fissures, and carrying low gold values.

DEPARTMENT OF MINES,
WAU,
MANDATED TERRITORY OF NEW GUINEA,
May 1, 1939.

MANGANESE IN A THERMAL SPRING IN WEST-CENTRAL UTAH.[1]

EUGENE CALLAGHAN AND H. E. THOMAS.

ABSTRACT.

The hot spring north of Delta, Utah, is of particular interest because it has yielded commercial manganese ore; 715 tons of manganese oxide ore that averaged 20% manganese and 0.26% sulphur is recorded. The deposits occur as a thin bed and as lenses and nodules in a dome about 1,600 feet across and 15 feet high that has been formed subsequent to the dessication of Pleistocene Lake Bonneville. The alkaline hot waters, which reach temperatures of 182° F. and have a total discharge of over 1,200 gallons a minute, average 3,900 parts per million in dissolved solids, with NaCl, $CaSO_4$, $MgCl_2$, and $CaCO_3$. Five complete analyses show a manganese content of from 0 to 1.2 parts per million. Nevertheless, no appreciable manganese seems to be precipitating at present. The bed of manganese and iron oxides is scarcely more than a foot thick and is mostly covered by porous calcite. The ore is a porous aggregate of psilomelane and pyrolusite in which the vugs are lined with limonite. These minerals have been formed through the action of hot alkaline solutions over a long period; the original mineral was probably wad. The barium oxide is believed to be chemically combined with the manganese oxides. Probably all these materials have been leached from underlying rocks or deposits by hot circulating groundwaters and may not have a magmatic source.

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[1] Published with permission of the Director, Geological Survey, United States Department of the Interior.

LOCATION.

THE hot spring in Juab County, 19 miles in a direct line north of Delta, Utah (Fig. 1), is of interest in that its deposits have

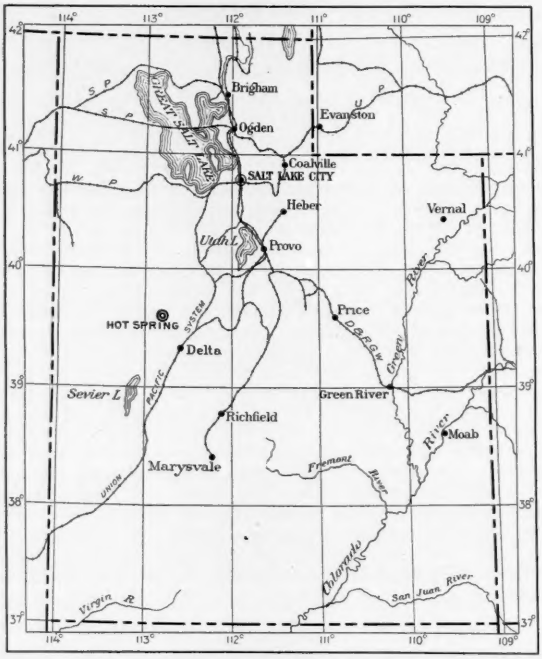


FIG. 1. Index map of Utah showing location of the Hot Springs.

been the source of the only commercially exploited body of manganese ore associated with a thermal spring, so far as the writers are aware. In 1929 and 1930, 715 tons of ore that averaged about 20 per cent manganese and 0.26 per cent sulphur was obtained from shallow pits in the hot spring deposit. No distinguishing name has been given to the hot spring; it is shown on maps and known to the local residents simply as the Hot Springs. However, it seems advisable to apply a distinct name;

the name Abraham is chosen as distinct, though the village of that name is several miles away. The Abraham Hot Spring is reached from Delta, the shipping point, by an unimproved desert road that is impassible in wet weather. The hot spring was doubtless discovered by early explorers of the region. It is briefly described by Gilbert [2] in his comment on the Fumarole Butte lava field, and mentioned in other publications.[3] The late W. R. Black is credited with the discovery of manganese in the spring deposit, and he with Mr. Fred Staats performed the exploratory work that has yielded the ore.

SURFACE FEATURES.

The Abraham Hot Spring issues from a low dome about 1,600 feet in diameter and about 15 feet above the gently sloping plain of the Sevier Desert (Fig. 2). A thousand feet west of the springs the plain ends abruptly against the steep front of a basaltic table land, which rises 50 to 100 feet above the plain (Fig. 3). The basalt is part of a flow or series of flows that is deeply eroded and shows strandlines of Pleistocene Lake Bonneville (Fig. 3). The margins of the basaltic table land are very irregular, and the Hot Springs are opposite a bay in the basalt front and about in line with two jutting points. The lake plain around the table land is nearly level, but contains many shallow playas, channels, hummocks, and sand dunes. East of the hot spring is the "Old River Bed," a channel excavated by the stream that drained the Sevier Lake basin northward during the waning stages of Pleistocene Lake Bonneville.[4]

[2] Gilbert, G. K., Lake Bonneville: U. S. Geol. Survey Mon. 1, pp. 332–335, 1890.

[3] Peale, A. C., Lists and analyses of the mineral springs of the United States: U. S. Geol. Survey Bull. 32, p. 185, 1886; Meinzer, O. E., Ground water in Juab, Millard, and Iron counties, Utah: U. S. Geol. Survey Water-Supply Paper 277, pp. 43 and 44, 1913; Stearns, N. D., Stearns, H. T., and Waring, G. A., Thermal springs in the United States: U. S. Geol. Survey Water-Supply Paper 679, pp. 108, 109, 181, 1937.

[4] Gilbert, G. K., op. cit., pp. 181–184, 1890.

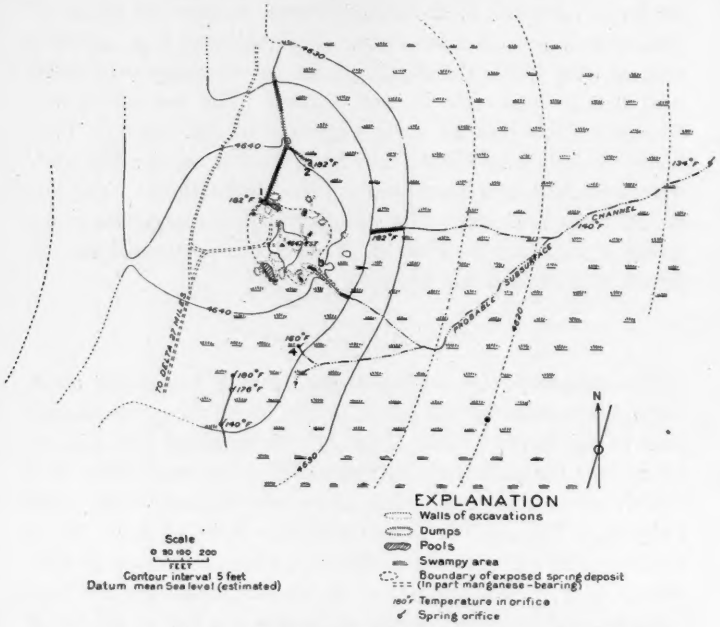


FIG. 2. Map of the Abraham Hot Spring dome, Juab County, Utah.

GEOLOGY.

The basalt flow or flows, the oldest rocks exposed, are regarded by Gilbert [5] as Tertiary; they may be of early or middle Pleistocene age, but are definitely pre-Bonneville. Fumarole Butte, about 4 miles northwest of the Hot Springs, was regarded by Gilbert [6] as the location of the vent from which the flows of the table land issued. At the time of Gilbert's visit, warm, moist air issued from crevices in this volcanic plug. The plain of the Sevier Desert is underlain by unconsolidated sediments of Lake Bonneville, but these doubtless are underlain by earlier Pleistocene and Tertiary sediments and volcanic rocks, which lie upon a base-

[5] Gilbert, G. K., op. cit., p. 334, 1890.
[6] Gilbert, G. K., op. cit., pp. 332–335, 1890.

FIG. 3. View of the Abraham Hot Spring dome from the south, showing the margin of the basaltic table land marked by strandlines of Pleistocene Lake Bonneville.

ment of much older rocks. No definite evidence of a fault line was seen in the vicinity of the springs.

HOT SPRING WATERS.

Before diversion through excavations incidental to mining and drainage (Figs. 2 and 4), the waters issued from orifices at the top as well as on the slopes of the hot spring dome. The flow from the central part of the dome now comes from orifices and ditches and pits. However, many vents appear in the marshy ground to the south and east of the central part and from some of these the water issues only to disappear promptly and reappear elsewhere. The largest volume of water issues from an orifice at the eastern edge of the area shown in Fig. 2, but, as it has a lower temperature than most of the others, it is regarded as an aggregation of the flow of most of the higher orifices. The position of a probable subsurface channel leading to the large orifice is shown in Fig. 2. The water, too highly mineralized for irrigation or stock-watering, disappears in the plain to the east of the spring. Temperatures measured in a number of vents were

found to range between 110° and 182° F., and several are recorded on the map (Fig. 2). The maximum temperature is about 20° below the boiling point at this altitude.

The abundance of vents, their appearance on nearly flat marshy ground, and the disappearance and reappearance of the waters prevented accurate measurements of the total discharge. The ditches in the central part of the dome were found to discharge about 550 gallons a minute, and the total discharge is estimated to be somewhat in excess of 1,200 gallons a minute or 2.7 cubic feet a second. These measurements were made in July and August; nothing is known to the writers of seasonal variation of discharge.

TABLE 1.

ANALYSES OF WATER FROM ABRAHAM HOT SPRINGS, JUAB COUNTY, UTAH.

Samples collected by H. E. Thomas, August 1938. N. A. Talvitie and M. D. Foster, analysts.

(Parts per million)

Description (see Fig. 2)	Total Dissolved Solids	SiO_2	Fe	Mn	Ca	Mg	Na K	HCO_3	SO_4	Cl	NO_3	Total Hardness $CaCO_3$
1. Orifice in west fork of north ditch	3907	60	—	.3	358	54	880	184	714	1510	.0	1116
2. Orifice in east fork of north ditch	3796	66	.67	.65	350	52	854	168	705	1470	.0	1088
	3840	61	—	.65	351	52	841	158	702	1460	.0	1091
3. Orifice of southeast ditch	3980	68	—	.35	359	54	879	158	726	1520	.0	1119
4. Orifice in swamp south of deposits	4015	61	—	1.20	362	56	883	168	722	1535	.0	1135

The analyses given above (Table 1) show that the total dissolved solids and the proportions of the various constituents in the water are remarkably uniform. The constituents that would form the principal solids on crystallizing would be, in descending order of abundance, NaCl, $CaSO_4$, $MgCl_2$, and $CaCO_3$. Of these only $CaCO_3$ precipitates readily from the hot waters to make appreciable deposits. However, the water has a salty taste, and gypsum is deposited on relatively cool surfaces. The HCO_3 radicle shows that the waters are definitely alkaline.

Though the ground and the orifice from which sample 1 (Fig. 2) was taken show the most manganese, that sample has, with two exceptions, the least manganese of all those tested. Of these, sample 4, from the swampy area south of the summit of the dome, contains the most manganese; 1.2 parts per million. Hewett [7] has pointed out that the maximum content of manganese that has been found in spring waters is about 117 parts per million, and that in river waters in the temperate zone the manganese content commonly ranges from 0.5 to 5 parts per million. The waters of Hot Springs, Arkansas, contain 0.3 part per million of manganese,[8] and it is noteworthy that D. F. Hewett [9] observed a vein of manganese oxides 2 to 3 feet wide near Spring 23 of the Hot Springs group. The waters of the Abraham Hot Spring are similar to well waters in the Sevier Desert [10] in the dominance of the main constituents. However, the mineral content of the hot waters of the deep well at Neels,[11] 40 miles south of the Abraham Hot Spring, closely resembles that of the hot spring, both in proportion and total amount. Manganese was not determined, however.

SPRING DEPOSITS.

The Abraham Hot Spring dome is built up of materials brought up by the hot waters in solution and precipitated at the surface together with sand and silt brought in by the wind and held by the moisture and vegetation. In only a small area at the summit of the dome (Fig. 2) is the solid deposit exposed; the remainder of the area is soft sand and silt, material that, in the swampy area, slumps readily even on very gentle slopes.

The shallow excavations (Fig. 4) reveal the nature of the upper part of the spring deposit. At the south side of the north

[7] Hewett, D. F., Manganese in sediments, in Twenhofel, W. H., Treatise on sedimentation, The Williams and Wilkins Co., Baltimore, p. 563, 1932.

[8] National Park Service, Hot Springs National Park, Arkansas, general information regarding, p. 9, 1933.

[9] Hewett, D. F., personal communication.

[10] Meinzer, O. E., op. cit., pp. 116–117, 1911; Lee, W. T., Water resources of Beaver Valley, Utah: U. S. Geol. Survey, Water-Supply Paper 217, p. 51, 1908.

[11] Lee, W. T., op. cit., p. 51, 1908.

pit, the wall is made up of brown clay at the base, 1.1 feet of black, vuggy manganese ore, and 1.3 feet of sand, clay, iron oxide, and porous calcite at the top. At the north side of the

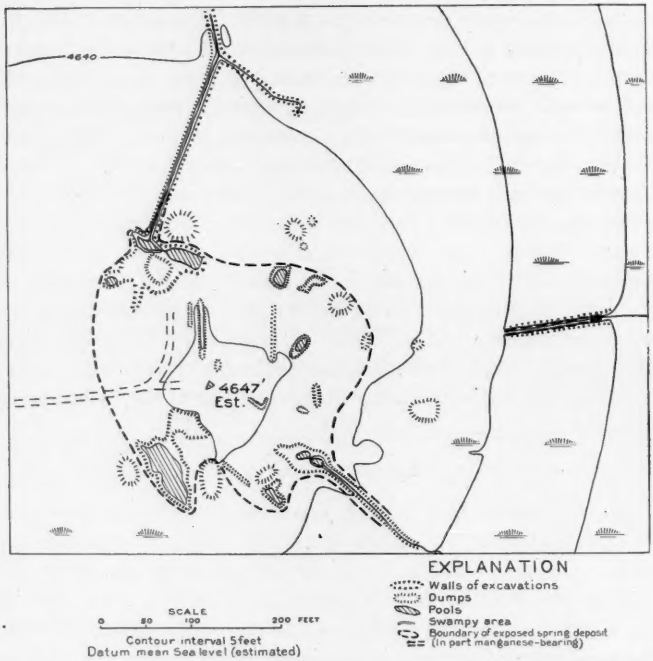


FIG. 4. Map of central part of Hot Springs dome showing details of excavations and outline of spring deposit.

same pit, the manganese has pinched out, and the brown clay is overlain successively by 0.5 foot of red clay, 0.2 foot of clay with small amounts of black oxides of manganese and iron, and 0.5 foot of porous calcite at the top. In the pit on the southwest side of the dome a surface coating of 0.6 foot of porous calcite is underlain by 1.6 feet of red and black material, and 1 foot of material containing small lenses of manganese oxides. In the

excavation south of the center of the dome, the surface coating of calcite is 1 foot thick, and is underlain by 2 feet of red and black nodular material. These sections of the walls of the pits indicate that the deposition of the manganese was a distinct episode in the history of the spring, and that shallow aprons of manganese oxides must have been laid down on what was then the surface of the dome. The ensuing history of the spring favored the deposition of calcium carbonate with small amounts of iron oxides. Nevertheless, the hot waters are still carrying manganese in solution.

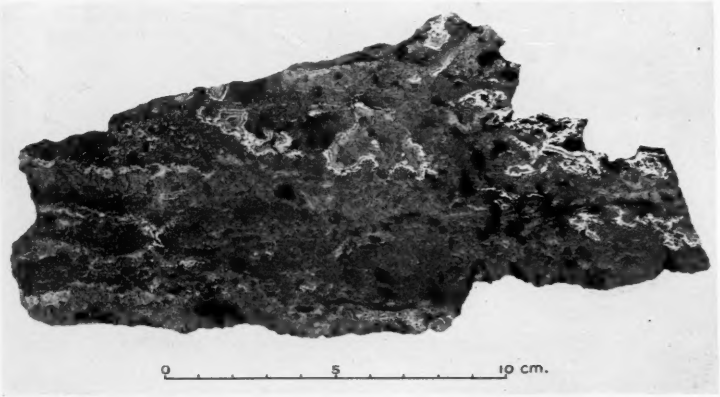


FIG. 5. Porous and vuggy calcite and limonite (white bands or crusts under reflected light) from upper part of Abraham Hot Spring deposit. Two varieties of calcite are shown, one dark because of a fine dust, the other white and filling vugs. The limonite forms crusts around vugs, filled by later calcite.

At present, calcium carbonate is being deposited as fibrous aragonite in the ditches in swiftly flowing hot water. However, the material making up the upper crust of the dome is now calcite, which has probably in part been formed by recrystallization of aragonite. The continuous supply of hot water has doubtless favored mineral changes. The brownish calcite, shown on Fig.

5 as the darker material, was evidently the first deposited or the first changed from original aragonite. It is veined and possibly partly replaced by later white calcite. The white calcite fills vugs where it is later than limonite that coats some of the cavities. The calcite is layered parallel to the surface of the dome, is porous, and some of its layers have a columnar structure that is now an aggregate of equant calcite crystals. No barite was detected in this material nor in the manganese ore, and only 0.67 per cent BaO was found in the part soluble in HCl.

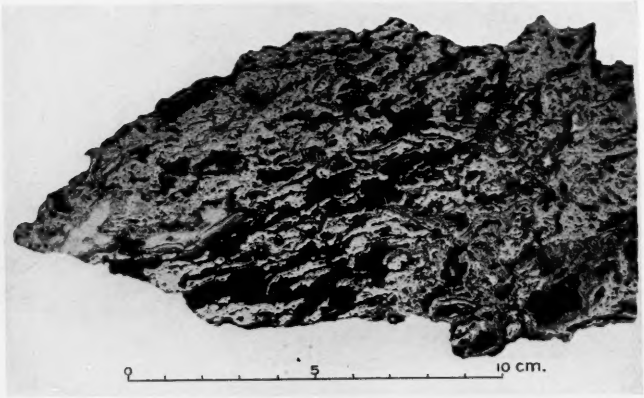


FIG. 6. Manganese ore from Abraham Hot Spring deposit in reflected light. Limonite crusts (dark) surround most of the cavities (black). Calcite fills a few vugs; the remainder is a mixture of psilomelane and pyrolusite.

The specimen shown in Fig. 6 represents the best-appearing material seen, and was taken from the south side of the north pit. An analysis representing the full thickness of 1.1 foot at this point is given herewith (Table 2). The manganese ore, as shown in Fig. 6, is exceedingly porous and vuggy, although some of the cavities are filled with white calcite. Many of the cavities are lined with botryoidal crusts of limonite, which in itself contains thin bands and spherulitic bodies of goethite. The metal-

TABLE 2.

ANALYSIS OF MANGANESE ORE FROM ABRAHAM HOT SPRING DEPOSIT, JUAB COUNTY, UTAH. J. J. Fahey, analyst.

MnO	42.92 (33.24 Mn)
Fe_2O_3	17.93
BaO	4.28
SiO_2	2.42
CaO	5.50
CO_2	5.48
SO_3	.43 (.17 S)
H_2O^-	.76
H_2O^+	6.69
	86.41
PbO	less than 0.01
WO_3	none

lic material that appears light in Fig. 6 is a mixture of manganese oxides which, under the reflecting microscope, are identified as psilomelane and pyrolusite. The bulk of the material considered to be psilomelane is massive, but is somewhat more anisotropic and coarser grained than analyzed specimens of psilomelane with which it was compared though by no means as strongly anisotropic as manganite or pyrolusite. Within the psilomelane are small groups of needles, which seem to fill vugs and which resemble closely analyzed specimens of pyrolusite. No other minerals were identified.

With reference to the analysis, it seems that there is sufficient hydrous iron oxide in the specimen to account for the iron oxide. Calcite accounts for most of the lime and carbon dioxide, and the SO_3 is probably present as gypsum. The content of BaO, which is characteristic of many manganese deposits is a point of special interest. As no barite is present, and as the calcite was found to contain only 0.67 percent of BaO, one is forced to the conclusion that the BaO is chemically combined or associated with either the iron or, more probably, the manganese oxides. It will be remembered in this connection that the manganese mineral hollandite may contain more than 17 per cent BaO. As lead has been found in many manganese oxide deposits, and as tungsten has been found in some, both these metals were sought; but results were negative.

ORIGIN.

It is obvious that, with the exception of detrital material, the minerals of the Abraham Hot Spring deposit were precipitated from the hot waters when they reached the surface. The restriction of manganese to a single bed or horizon indicates that extensive deposition of manganese oxides and to a lesser extent of iron oxides was a distinct episode in the history of the spring, even though the hot waters are still carrying some manganese in solution. The present mineral composition of the deposit needs some interpretation, however. It is suggested that the manganese was first laid down as earthy wad, and that a crystallization to psilomelane and pyrolusite with coatings of iron oxide has been effected by the long application of heat and passage of solutions since the manganese was deposited and covered by other materials. Much of the calcite must have been formed by recrystallization of aragonite, but the white calcite has very probably been deposited directly from solution. The deposit is a recent one, formed after the desiccation of Pleistocene Lake Bonneville. It is unlikely that chemical deposits would have been precipitated in the shape of a dome in fresh or nearly fresh lakewater.

The ultimate origin of the deposits is wholly a matter of conjecture. As the major dissolved solids in the hot spring waters are the same as those in well waters in this region, it seems probable that all the constituents have been leached by hot ground waters from the rocks through which they passed and have been deposited on reaching the atmosphere. None of the elements demands an immediate igneous source, but the possibility of such a source of manganese and barium cannot be eliminated. Though chlorides would be regarded as indicators of a magmatic contribution in some areas, the passage of these waters through beds that doubtless contain salt and gypsum makes it impossible to demonstrate an igneous contribution.

The data obtained on this spring yield no definite proof or generalization concerning the origin of hot springs in the Great Basin or the hot-spring problem[12] in general. Therefore, it

[12] Day, A. L., The hot-spring problem: Geol. Soc. Amer. Bull., 50: 317–336, 1939.

seems sufficient to say here that the Abraham Hot Spring waters are regarded simply as surface or meteoric waters that percolate downward to sufficiently great depths to attain a high temperature, and return to the surface through a convenient conduit provided by a fracture or a volcanic pipe. The hydrostatic head must be provided by the waters entering gravels of the bases of the ranges and following porous layers between impermeable clay beds. It is of especial interest to note in this connection the indications of an abnormally high geothermal gradient in this region. Lee [13] found that temperatures of well waters in Beaver County southeast of the Hot Springs were abnormally high. The waters from all horizons in the deep well at Neels, 40 miles south of the Abraham Hot Springs, were hot and the mineral content closely resembled that of the Abraham Hot Springs. Investigations by one of the writers (Thomas) of a dozen wells, which reach a maximum depth of 580 feet, in the region around Delta show an average gradient of 1° F. for each 30 feet of depth. If this rate of increase were constant, the rock temperature at a depth of somewhat less than 4,000 feet would be equal to that of the Abraham Hot Spring at the surface.

The presence of the hot spring and the escape of warm, moist air from the volcanic neck of Fumarole Butte were regarded by Gilbert [14] as indications of the persistence of volcanic heat. Although there have been volcanic eruptions in the region in post-Bonneville time, the local volcanic activity has not been great. Nevertheless, the abnormal geothermal gradient may be due to escape of heat from an underlying dormant magma. Considering the relatively small amount of water, it seems that its heat could be derived from the rocks through which it passes rather than from superheated magmatic steam.[15] The lack of demonstrable volcanic materials in the discharge of the Abraham Hot Spring makes it impossible to prove a magmatic connection, even though the abnormal geothermal gradient and the presence of recent extinct craters points to a magmatic heat supply.

[13] Lee, W. T., Water resources of Beaver Valley, Utah: U. S. Geol. Survey Water-Supply Paper 217, pp. 32–37, 1908.

[14] Gilbert, G. K., op. cit., p. 334, 1890.

[15] Day, A. L., op. cit., p. 329, 1939.

COMPARISON WITH OTHER DEPOSITS IN WHICH MANGANESE OCCURS.

Manganese oxides have been observed in other spring deposits. Lindgren [16] has described a hot spring in central Bolivia in which slightly salty water issues from several vents at a temperature of about 140° F. The total discharge is at least 150 gallons a minute. The deposits are chiefly porous calcite with brown streaked opal, masses of psilomelane, and streaks of crystalline barite and calcite. Tests for tungsten showed the presence of about 0.5 percent WO_3.

A deposit [17] on the bottom of a glaciated valley near Kaslo, British Columbia, has yielded about a thousand tons of manganese ore that is said to have averaged from 45 to 50 per cent manganese, although some samples contained as much as 60 per cent manganese. The deposits underlie two areas; one contains 2½ acres and the other contains 5½ acres. The manganese oxide forms a bed from a few inches to 3 feet in thickness, and is associated with calcareous tufa, hydrous iron oxides, and clayey layers. The manganese is of the wad or bog type, and has been deposited in swampy ground by cold mineral springs.

The deposit of manganese oxides near Golconda, Nevada, which is associated with the sediments of Pleistocene Lake Lahontan, was considered by Penrose [18] to be a spring deposit. However, on the basis of later work, Pardee [19] traced the manganese to a vein, which had reopened and permitted manganiferous

[16] Lindgren, Waldemar, A recent deposit of a thermal spring in Bolivia: ECON. GEOL., 17: 201–206, 1922.

[17] Minister of Mines, B. C., Ann. Repts., pp. 156, 185, 1917; pp. 160–161, 1918; p. 120, 1919; Cairnes, C. ., in Hanson, G., Manganese deposits of Canada: Can. Geol. Surv., Econ. Geol. ser., no. 12, pp. 107—111, 1932; Bancroft, M. F., Investigations in the Slocan district, B. C.: Can. Geol. Surv., Sum. Rept., 1817, pt. b, pp. 30–33, 1918; Cairnes, C. E., Slocan mining camp, British Columbia: Can. Geol. Surv., Mem. 173, p. 109, 1934.

[18] Penrose, R. A. F., Jr., A Pleistocene manganese deposit near Golconda, Nevada: Jour. Geol., 1: 275–282, 1893; Manganese, its uses, ores, and deposits: Ark. Geol. Survey Ann. Rept. for 1890, vol. 1, p. 470, 1893; Harder, E. C., Manganese deposits of the United States: U. S. Geol. Survey Bull. 427, pp. 153–157, 1910.

[19] Pardee, J. T., and Jones, E. L., Jr., Deposits of manganese ore in Nevada: U. S. Geol. Survey Bull. 710, pp. 235–238, 1920.

solutions to reach the surface and the precipitate became incorporated in the lake sediments. Hewett [20] has described a bedded deposit of manganese oxides in Bannock County, Idaho, which is associated with Pleistocene lake beds. No definite hot spring source was recognizable here, however.

ECONOMIC CONSIDERATIONS.

The total yield of nearly 715 tons of ore from the shallow pits shown in Fig. 4 is set forth in detail in Table 3. Additional

TABLE 3.

SHIPMENTS FROM ABRAHAM HOT SPRING DEPOSIT (IRON KING MINE), JUAB COUNTY, UTAH. Furnished by Mr. Fred Staats.

Date	Dry Weight, Tons	Per Cent Mn	Per Cent H_2O	Per Cent Sulphur
Dec. 16, 1929.....	40.116	19.4	6.6	.55
Jan. 10, 1930.....	49.894	12.6	8.2	.25
Jan. 20, 1930.....	46.209	22.6	5.6	.20
Jan. 30, 1930.....	41.075	19.0	5.9	.09
Feb. 11, 1930.....	62.311	25.5	2.7	.20
Apr. 18, 1930.....	55.955	26.5	5.0	.42
Apr. 30, 1930.....	53.591	20.8	5.3	.15
Sept. 17, 1930.....	46.307	21.8	13.25	.08
Sept. 17, 1930.....	50.125	20.8	12.0	.38
Sept. 25, 1930.....	58.236	25.2	8.75	.15
Sept. 25, 1930.....	40.493	21.4	8.2	.12
Sept. 30, 1930.....	29.929	16.4	13.6	.70
Sept. 30, 1930.....	35.195	15.6	11.55	.47
Oct. 30, 1930.....	29.401	17.0	8.75	.14
Nov. 20, 1930.....	36.333	23.3	9.1	.18
Dec. 12, 1930.....	39.401	17.7	11.2	.10
Total.....	714.571			

exploratory pits have been dug over most of the accessible part of the dome. Further prospecting could be done, but it seems probable that the greater part of the better material has been removed. The dome should be tested with the auger to depths of at least 15 feet to determine whether other manganese layers underlie the one mined. Any attempt at mining, however, must take into account the large supply of hot water. Though the

[20] Hewett, D. F., A manganese deposit of Pleistocene age in Bannock County, Idaho: U. S. Geol. Survey Bull. 795, pp. 211–218, 1928.

deposit is of interest as one whose immediate source is unquestionable, it is not regarded as the reserve of any considerable quantity of manganese. It shows, however, that other hot spring deposits should be checked carefully for workable bodies of manganese.

ACKNOWLEDGMENTS.

This study was under the direction of Mr. D. F. Hewett, and the authors are indebted to him and to Mr. O. E. Meinzer for critical reading of the paper. Mr. V. C. Kelley assisted with the preparation of the map, G. H. Taylor assisted with the discharge measurements, Miss M. D. Foster helped materially in interpretation of the water analyses and J. J. Fahey with the ore analysis; C. F. Park, Jr., aided in the identification of the minerals, and N. W. Shupe made the photographs of the polished surfaces. The writers are particularly indebted to Mr. Fred Staats for drawing their attention to the hot spring and for the production table.

U. S. GEOLOGICAL SURVEY,
WASHINGTON, D. C.,
CEDAR CITY, UTAH,
Aug. 10, 1939.

MAGNETITE AND HEMATITE VEINS IN TRIASSIC LAVAS OF NOVA SCOTIA.

A. P. HORNOR, JR.

ABSTRACT.

Some small iron-bearing veins in the Triassic basalts of Western Nova Scotia are described. Amethystine quartz, zeolites, specular hematite, and dendritic magnetite crystals characterize these veins. The mineral paragenesis is traced. An analysis of the magnetite is presented which reveals a considerable magnesia content. The origin and formation of the veins are discussed with a view to correlating the composition of the magnetite with the type of country rock.

INTRODUCTION.

THE Triassic lava flows of Western Nova Scotia form the southern shore of the Bay of Fundy. They occupy a narrow strip two to five miles wide extending from Brier Island northeastward and passing beneath the Minas Basin to the mainland to form Gerrish's Mountain, a total length of 150 miles. In this area iron ore veins are found. The specimens on which this report is based were collected in the summer of 1933 by Professor W. H. Newhouse of the Massachusetts Institute of Technology from three occurrences (1) near Waterford, Digby County in the southern portion of this area, (2) near Lakeville, Kings County in the north-central portion, and (3) at Gerrish's Mountain at the northern extremity of the area.

To Professor W. H. Newhouse, who suggested this work, the writer is indebted for many ideas tested in this study, and for guidance and assistance. For the description of the veins in the field and for the general geology of the region the writer has drawn on the literature[1] and conversations with Professor Newhouse.

[1] Bailey, L. W., Report on the geology of south-western Nova Scotia, Can. Geol. Surv. Annual Report, IX: 1896. Dawson, Sir J. W., Acadian Geology, Macmillan & Co., 1868. Powers, Sidney, The Acadian Triassic, Journal of Geology, 24: 1916.

GEOLOGY.

The Triassic of Eastern North America makes up the Newark Group which in the Acadian area is divided into three formations: [2]

Scots Bay formation—a calcareous, white sandstone.
North Mountain Basalt—a succession of lava flows.
Annapolis formation—red beds, largely calcareous.

The lava flows overlie and are in part intercalated with the red sandstones and shales, and present topographic features much resembling the trap ridges of the same age in Connecticut and New Jersey. In Nova Scotia the prevailing dip is northwestward. Unconformably beneath the Triassic, the youngest rocks of the region, are metamorphosed Paleozoic sediments of various types. The Paleozoics lie against and are in part intruded by a granite batholith of Devonian age, the so-called granite axis of Central Nova Scotia. Underlying the Paleozoics is the pre-Cambrian Gold Bearing Series, also cut by the Devonian granite. The entire area has been thoroughly glaciated, as evidenced by fiords along the Southern coast, and by abundant moraines, erratics and striæ.

VEINS AND COUNTRY ROCK.

Country Rock.

The rocks with which the veins are associated are intercalated massive and columnar basalt with ashy, scoriaceous and amygdaloidal beds. The massive layers predominate, and it is in these that most of the iron bearing veins are found. Bailey [3] gives a field description of the most abundant and characteristic rock:

> . . . a compact, crystalline admixture of augite and feldspar, of a dark greenish-gray tint and a granular texture, but very hard, without stratification and with a tendency, which is sometimes very marked, to exhibit a jointed or columnar structure . . . in vertical bluffs . . . resembling, though on a much smaller scale, those of the Palisades of the Hudson.

[2] Powers, Sidney, The Acadian Triassic, Jour. Geol., 24: 1916, p. 6.

[3] Bailey, L. W., Report on the geology of south-western Nova Scotia, Can. Geol. Surv. Ann. Rep., IX: 1896, p. 129M.

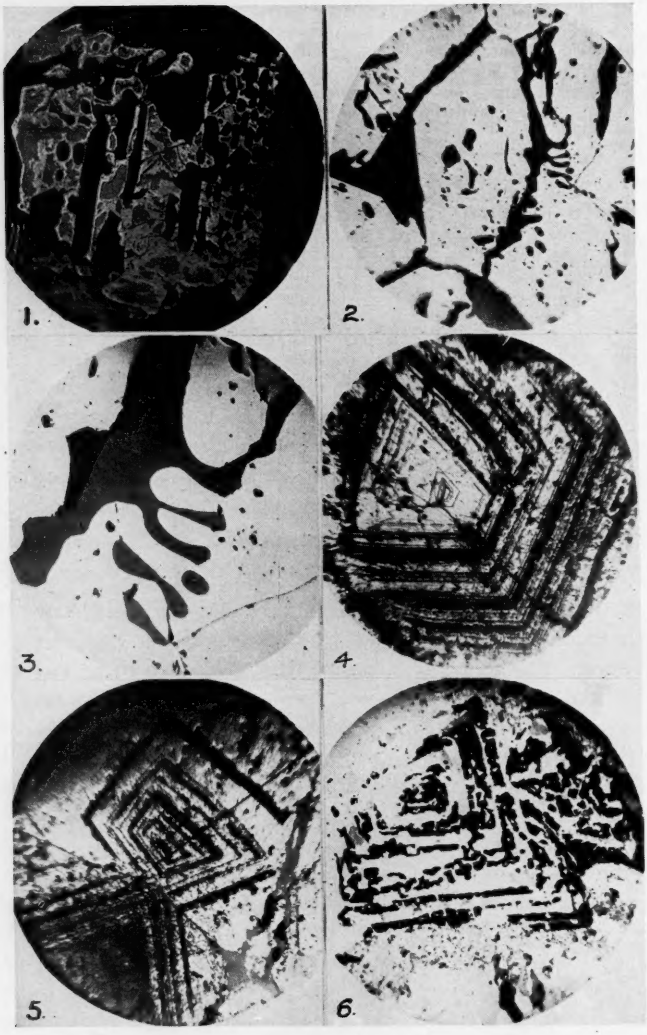
. . . The same joint planes are also frequently marked by the presence of minute quartzose veins, while across the whole mass run much more considerable veins of like nature, but more variable in coloration, producing agates and jaspers beautifully clouded and banded. With these, at a number of points, are veins wholly or in part composed of magnetite or octahedral hematite (martite) probably a pseudomorph of magnetite.

Microscopically the massive basalt shows a fine grained, ophitic texture. Plagioclase is more abundant than augite and magnetite is the most abundant accessory mineral. An unaltered sample from the Lakeville occurrence shows in thin section zoned plagioclase and a colorless pyroxene exhibiting extinction angles for average augite. Magnetite appears as inclusions in the other minerals as minute euhedral grains which in the augite are typically arranged in chain-like groups. An altered specimen from near a vein at Waterford shows clouded plagioclase and considerable amounts of a fibrous, green, pleochroic mineral and a brownish-colored amorphous material, both probably developed from the destruction of the augite. Alteration has not proceeded far enough to obliterate completely the texture of the unaltered basalt.

The Veins.

A field description of the veins by Bailey is quoted above in connection with the lavas of which they form a characteristic feature. The veins range in size from a fraction of an inch up to a foot or more in width and from a few feet to fifty feet in length. In former times these veins were exploited on a small scale for iron ore.

The veins trend generally transverse to such stratification as the rocks may exhibit, and carry iron minerals with various others along their length. Their arrangement according to a rough pattern, as suggested by Bailey, indicates a relationship to joints. Vugs and geodes are common and form the wider portions of the veins. The physical characteristics and the relative abundance of the minerals varies from place to place along the veins, and massive magnetite or hematite gives way to lean mixtures of these minerals with the gangue in other portions of the same vein.



FIGS. 1–6.

Magnetite.—This mineral was identified in the specimens from all three localities. At Waterford magnetite was observed with calcite as small crystals, in some cases as perfect octahedra. A red powder coats the crystals and the mineral gives a red streak. Polished sections (Fig. 1) proved the magnetite to be altering to hematite (martite). In this photograph the dark, irregular patches are magnetite, and the lighter areas surrounding the dark are hematite. The field is calcite. Replacement has apparently progressed irregularly through the crystals beginning from the outer surfaces. In polarized light the hematite areas flash irregularly over a single fragment of magnetite indicating that the replacing hematite is in the form of a number of individual grains. The skeletal shape of the crystal suggests that the original magnetite was in the form of the dendritic crystals to be described from the Lakeville and Gerrish's Mountain veins. In thin section, magnetite cuts across the cleavage of calcite, and in general gives no evidence of replacing calcite.

The magnetite from Lakeville and Gerrish's Mountain occurs in individual octahedral crystals of considerable size or in massive aggregates loosely cemented to the basalt walls. It is deep black in color, has a pitch-like luster and is highly magnetic. The massive mineral commonly exhibits a conchoidal fracture that appears iridescent in reflected light. Wherever observed, the crystal faces are striated, in most cases coarsely enough to be observed with the naked eye. Quartz is present and in the massive aggregates forms in thin films coating the surfaces between

FIG. 1. Polished section showing hematite replacing dendritic (?) magnetite crystals in calcite gangue (black). Irregular dark areas magnetite, light hematite, × 20.

FIG. 2. Polished section of massive magnetite. Magnetite crystals (white) are coated by films of quartz (black). Spatulate shaped projections of magnetite penetrate into the quartz between grains, × 20.

FIG. 3. Enlarged portion of the field shown in Fig. 2 to show details of the spatulate shaped projections along the edges of magnetite crystals, × 80.

FIGS. 4 and 5. Etched polished sections of massive magnetite showing zonal structure of the crystals, × 20.

FIG. 6. Thin section of dendritic magnetite crystal in quartz, crossed nicols × 15.

crystals and as irregular veinlets cutting them. In polished sections, the magnetite appears homogenous with no indication of exsolution intergrowths, as shown in Fig. 2. Certain of the crystal boundaries near the center of the field in this photograph show spatulate shaped projections of magnetite extending into the quartz filling between grains. Fig. 3 shows a portion of the same area with higher magnification. Other sections reveal a zonal structure which is brought out more clearly by etching. Figs. 4 and 5 illustrate zoning in etch specimens from Lakeville. Thin sections of massive aggregates reveal the truly skeletal form of the crystals. An extreme example is shown in Fig. 6. The appearance is that of a section cut through a nest of boxes. Quartz occupies the spaces between the ribs of magnetite. In other sections of more fully developed crystals, quartz veinlets are seen to cut and brcciate the magnetite.

The pronounced pitch-like luster and the zonal structure characteristic of the magnetite from Lakeville and Gerrish's Mountain suggested that the mineral might be of unusual composition. A carefully prepared sample of the pure mineral from Lakeville was analyzed with the results shown in Column I of Table I.

TABLE I.

	I	II	III	IV
Fe_2O_3	71.30	66.95	72.73	85.39
FeO	20.80	15.87	9.66	....
MgO	6.42	8.81	12.61	14.42
CaO	trace	....	....	....
TiO_2	....	0.89	0.46	....
MnO	0.03	....	0.12	....
V_2O_5	....	0.02	trace	....
P_2O_5	trace	....	....	....
SiO_2	1.40	....	....	....
Total	99.95	....	....	99.81

I. Magnetite from near Lakeville, Nova Scotia. Analysis by R. B. Ellestad, Univ. of Minn., Rock Analysis Laboratory.

II. Magnetite partial analysis from Ilimpeia River, Eastern Siberia. Sobolev, V., Iron ore deposits of the Ilimpeia River, Eastern Siberia. ECON. GEOL., 30: 1935, p. 787.

III. Magnetite partial analysis from Chunia River, Eastern Siberia. Sobolev, V., Idem, p. 787.

IV. Magnesioferrite from Vesuvius, average of five analyses. Doelter and Leitmeier, Hand. der Mineralchemie, 3: Pt. 2, p. 655.

The analysis shows an unusually high percentage of MgO for a normal magnetite. Probably this mineral should be regarded as an intermediate member of the magnetite-magnesioferrite group. The analyses given in columns II and III are of magnetite from veins in basalt in Eastern Siberia described by Sobolev [4] who classes the mineral as an intermediate member of this group. For comparison is shown in the last column the composition of magnesioferrite from the fumaroles of Vesuvius.

Hematite.—The mineral has been described as a pseudomorph (martite) of magnetite in the foregoing section. The specular variety of hematite was observed only in the specimens from Waterford. Here it occurs in thin, tabular flakes a few millimeters to a centimeter in length, generally of random orientation in a gangue of quartz and zeolite. In small veins, specularite crystals may extend perpendicularly from wall to wall. The flakes are of mirror-like brightness, steel-grey in color with no iridescence. When viewed in thin splinters the mineral shows a clear blood-red color. It is brittle and quite magnetic. The reason for the latter property was not explained. The mineral appears homogenous in polished section. Specular hematite was not observed in the same specimen with magnetite, and their correlation was not determined, but both minerals clearly preceded quartz and zeolite.

Apatite.—Apatite was observed in the specimens from Gerrish's Mountain as white, prismatic crystals up to a quarter of an inch in length, which occurred sparingly throughout the massive magnetite. Observed in thin section, distinct cleavage parallel to the length of the crystals is characteristic of the mineral. Apatite is believed to have formed contemporaneously with magnetite. No reaction along common boundaries of the two minerals was observed in thin section. Quartz veins cut and brecciate both minerals.

Calcite.—This mineral is abundant in the specimens from Waterford, occurring in rather perfect rhombs of a yellowish-red color. Here it appears to follow magnetite. Thin sections

[4] Sobolev, V., Iron ore deposits of the Ilimpeia River, Eastern Siberia, ECON. GEOL., 30: 1935.

of specimens from the same locality show calcite replaced by quartz. Calcite was observed in sections of massive magnetite from Gerrish's Mountain as tiny, highly-refringent, crystals possibly contemporaneous with magnetite. No calcite was identified from Lakeville.

Stilbite.—This is the only member of the zeolite group identified in the collection, and comes only from Waterford. No doubt other species do occur in these veins as a great number have been described from this region. In the Waterford specimens stilbite occurs in large rosettes or radiating clusters of blade-like crystals, flesh-pink or white in color, with a pearly luster, and vertically striated along their length. Blowpipe, chemical and optical data check fairly well with that given for stilbite. Hand specimens show stilbite clusters coated with layers of colloform silica. In thin sections quartz veinlets are seen to cut stilbite, and drusy quartz fills openings between crystals. In all sections observed the stilbite precedes quartz.

Quartz and Other Forms of Silica.—Many forms of silica were observed in the various specimens. Conspicuous is the amethystine variety of quartz in beautiful crystals of considerable size observed from Lakeville and Gerrish's Mountain. Vugs are filled with drusy quartz commonly deposited in several layers. The amethystine variety was observed to be the last layer of quartz deposited in these fillings and prisms of a delicate purple color with perfect crystal terminations commonly project into open spaces in the vugs. Colored and uncolored cryptocrystalline types of silica are also abundant and include jasper and banded calcedonic silica. A porous, sinter-like variety of silica was observed from Gerrish's Mountain. In some thin sections, quartz appears as a mosaic of interlocking crystals that produce the effect known as Airy's Spirals when the microscope stage is revolved in polarized light. This optical phenomenon has been ascribed to interpenetration of right and left handed portions united in the same crystal. This structure is common only to low temperature quartz. Quartz is clearly the last mineral of the series.

It encrusts the basalt walls and the other minerals and in tiny veinlets cuts through all earlier structures.

ORIGIN AND FORMATION OF THE VEINS.

The veins are undoubtedly related to the extrusion of the Triassic lavas, and were probably deposited during the period of cooling after the development of joints. To review the evidence; it is seen in the field that the veins are restricted to the area of the lavas and that later intrusives that could have caused the mineralization are lacking in this region. The minerals occur as crustifications on the vein walls. These crusts in the case of magnetite are formed of skeletal or dendritic crystals typical of minerals deposited rapidly in open space where diffusion of material is not uniform. Also to be emphasized is the high MgO content of the magnetite from these veins in basalt. Reference to the literature [5] shows that the mineral magnesioferrite is everywhere related to basic and alkaline magmas.

The mineral paragenesis is easily traced. Emanations from the cooling lavas probably ascended along open fissures. In the first or high temperature stage, the iron minerals, hematite and magnetite, with small amounts of apatite and probably some calcite, were deposited as crustifications on the walls. The succeeding stage at lower temperature was marked by the deposition of zeolites, quartz, in part of the amethystine variety, and colloform silica. A network of quartz veinlets cutting all earlier minerals closed the deposition.

SUMMARY.

Some small veins in Triassic basalt of Nova Scotia are described. Specular hematite, magnetite, zeolites, and amethystine quartz occur in these veins as an unique mineral assemblage. The magnetite proves to be a particularly interesting mineral in that it shows a characteristic dendritic crystal growth and an unusual composition. An analysis of the mineral shows a high

[5] Sobolev, V., Iron ore deposits of the Ilimpeia River, Eastern Siberia, ECON. GEOL., 30: 1935, p. 788.

percentage of magnesia indicating that it is not the normal magnetite, but an intermediate member of the magnetite-magnesioferrite group. This variation in composition is correlated with the source rock, and it is shown by a review of the literature that such variation is peculiar to magnetite formed from basic and alkaline magmas. The origin and formation of the veins are discussed, and they are believed to have deposited from emanations given off by the cooling lavas that ascended along open fissures.

POTOSI, BOLIVIA,
Aug. 10, 1939.

DISCUSSION AND COMMUNICATIONS

ALTERATION OF ILMENITE.

Sir: The communication of Joh. G. Koenigsberger on the Alteration of Ilmenite, on page 844 of the last number of this Journal, leads the writer to comment on this subject. The study of a large number of thin sections of altered basic pre-Cambrian rocks shows that leucoxene is a very common secondary mineral in basalts, diabases and gabbros carrying ilmenite or highly titaniferous magnetite as accessory minerals. In much of the leucoxene there is no evidence of crystals of any kind in the mass that preserves, in skeletal outline, the crystal fabric of the ilmenite and in some of it titanite or a similar mineral may be recognized. Just what the constituents of leucoxene are, is a controversial matter, as different mineralogists have identified titanite, anatase, perovskite and rutile from it. The rutile maye be relic needles from the ilmenite.

It has been a common practice to speak of leucoxene and other secondary minerals associated with it in the pre-Cambrian basic rocks as due to weathering. They may, however, be found in rocks beneath the reach of weathering processes, and this, coupled with our more advanced knowledge of the conditions of formation of such minerals as talc, serpentine and chlorite, leads one to question the correctness of this practice. The writer has reached the conclusion that leucoxene and the associated secondary minerals are in most cases at least due to igneous after-effects and not to weathering as the term is commonly used.

E. S. Moore.

University of Toronto,
November 11, 1939.

REVIEWS *

Market for Columbia River Hydroelectric Power Using Northwest Minerals. By EDWIN T. HODGE. Pp. 3472 (mimeo), illustrated. War Department, Corps of Engineers, U. S. Army, Office of Division Engineer, North Pacific Division, Portland, Oregon, January, 1938. Price, $27.00.

This report is one of a series of investigations of the economically available mineral deposits in the northwest and of their possible use in electrochemical and electro-metallurgical industries, that may be located in the lower Columbia River Valley. It was undertaken with a view to the development of a market, for the hydroelectric power from the Bonneville Dam. It was planned as a study of the mineral economics of the region.

The study concerns itself with the quantity, quality, transportation, industrial uses, and possible market areas for magnesia, silica, limestone, and clay. It gives transportation costs from the mineral deposits to probable manufacturing sites near Bonneville. Some processing costs are also given. Geologically, there is in the report very little information that is new but much widely scattered material has been brought together. In fact the report may be considered an inventory of northwest deposits of the minerals investigated.

Because the report is essentially a compilation of extracted material more care should have been taken to give credit and references by footnotes. A general list of references may be found in the appended bibliography but in the main body of the report whole pages are to be found reprinted verbatim from previous works with no indication as to their source. The same is true of many of the reproduced maps.

The format of the report is lamentable, particularly to librarians, who struggle with the ever present problem of space. The double-spaced typewritten lines are mimeographed on one side only of thick paper. Naturally the report is unduly bulky. It occupies fourteen and one-half inches of shelf space. Had it been printed or even photolithographed it probably would have contained only 800 instead of 3472 thicknesses of paper, which would have been of a much thinner type. In addition the maps and photographs are blurred and poorly reproduced.

* Books noted under *Reviews* and *Books Received* may be ordered through the Economic Geology Bookshop, W. S. Bayley, Urbana, Ill., but orders for official reports and single copies of Journals should be sent directly to their publishers.

The cumbersome size and inadequate references detract from the value of the report but in spite of these objections it remains an unsurpassed reference for the mineral economics of the region. It is divided into four sections; which are further divided into bound volumes. The divisions and their contents are:

Section I—Northwest Magnesia Ores, pp. 364, $3.75. Vol. I, pp. 173; Part I, Magnesite and Electro Industries, Part II, Sources of Raw Materials. Vol. II, pp. 174–364; Part III, Uses, Technology, Market.

Section II—Northwest Silica Materials, pp. 408, $3.75. Vol. I, pp. 175; Part I, Silica Localities of the Pacific Northwest. Vol. II, pp. 176–408; Part II, Silica Localities Other than the Pacific Northwest, Part III, Technology of Silica.

Section III—Northwest Limestones, pp. 621, $7.00. Vol. I, pp. 312; Part I, Limestones of the Northwest States. Vol. II, pp. 313–621; Part II, Other Limestone Occurrences Available to or Competitive with the Lower Columbia River Area, Part III, Uses, Technology, and Market of Limestone and Lime.

Section IV—Northwest Clays, pp. 1079, $12.50. Vol. I, pp. 126; Part I, Clays, Their Mining and Preparation. Vol. II, pp. 127–491; Part II, Uses of Clays. Vol. III, IV, pp. 492–804, 805–1079; Part III, Sources of Clay for Scheduled Uses. Part IV, History and Statistics of Clay, Part V, List of Research Activities and Bibliography.

VERNON E. SCHEID.

MOSCOW, IDAHO,
October 21, 1939.

Annual Reviews of Petroleum Technology. Vol. 4. F. H. GARNER, Editor. Pp. vii + 478. Institute of Petroleum, London, 1939. Price, $3.00.

This well-known review of petroleum technology covers the advances made in the subject during 1938. Its plan of presentation is similar to that of earlier volumes, but perhaps is a little more comprehensive.

After a brief resume of the advances made in the theories of petroleum origin and accumulation by Levorsen and general reviews of the extent of explorations and exploitation in the United States by Ver Wiebe and in other countries by Hobson, the main subject of the volume is developed by 25 specialists in 25 different phases, including among others, geophysics, drilling, production, transportation, refining, cracking, the properties of the different products, engines and lubrication, and ending with a review of the petroleum literature of the year and a statistical chapter.

W. S. BAYLEY.

Minerals Yearbook, 1939. Review of 1938, supervised by H. H. HUGHES. Pp. 1437. U. S. Bur. Mines, Washington, D. C., 1939. Price, $2.00.

This well known annual volume on U. S. and foreign mineral statistics contains some revision this year in the form of the introductory summary

of mineral statistics and, particularly, an excellent chapter on economic aspects of international mineral policies by J. S. McGrath. This deals with the mineral trade and resources of Germany, Italy, Poland and Hungary, the mineral resources gained from Czechoslovakia, and their bearing on the war. Under individual minerals, account is taken of the new conditions in Europe.

Terrestrial Magnetism and Electricity. Physics of the Earth, VIII. Edited by J. A. FLEMING. Pp. 784; illust. McGraw-Hill Book Co., New York, 1939. Price, $8.00.

This monographic work, under able editorship, covers the entire field. There are fourteen well known contributors, eight of whom are from the Department of Terrestrial Magnetism of the Carnegie Institution. The puzzling and complex nature of the earth's magnetic and electrical fields is unravelled so far as knowledge goes and directions for further research are indicated.

The contents may be best indicated by the chapter headings, as follows: Earth's Magnetism and Magnetic Surveys, J. A. Fleming; Magnetic Instruments, H. F. Johnson, J. A. Fleming and H. E. McComb; Magnetic Prospecting, C. A. Heiland; Atmospheric Electricity, O. H. Gish; Instruments in Observance of Atmospheric Electricity, O. W. Torreson; Earth Currents, W. J. Rooney; Earth Magnetism and its Changes, A. G. McNish; Problems of Terrestrial Magnetism and Electricity, J. Bartels; Radio Exploration of Outer Atmosphere, L. B. Berkner; Upper Atmosphere, E. O. Hulbert; Aurora Polaris, L. Vegard; Thunder-clouds, Shower-clouds and Electrical Effects, F. J. Schonland; Biographical Notes and References, H. D. Harradon.

The book is comprehensive and is an outstanding contribution to this field. There is a valuable classified bibliography of 1523 references.

Earthquakes and Other Earth Movements. By JOHN MILNE. New edit. rev. and rewritten by A. W. Lee. Pp. 244; Figs., 83. Blakiston's Sons and Co., Philadelphia, 1939. Price, $3.50.

The new edition brings up to date, by entire rewriting, Milne's well known early volume on earthquakes, and his subsequent supplements on seismology. Much of the data has been obtained from English observations. The 16 chapters deal with the following subjects: Observations of Earthquake Phenomena, Effects, Earthquake Construction, Seismographs, Elastic Waves, Records, Analysis of Records, Catalogue of Earthquakes, Distribution in Space and Time, Early Beliefs of Causes, Anaseisms and Kataseisms, Mechanism, Microseismic Disturbances, Seismic Methods of Geophysical Prospecting, Summaries and Tables. The book is well written and illustrated but suffers the restriction of an attempt to revise a book long out of date instead of blazing a new trail.

BOOKS RECEIVED.

DAVID GALLAGHER.

Contributions a la Géologie de la Pologne, 1937–38. Pp. 56; figs. 9. Inst. Géol. de Pologne Bull. 9, Warsaw, 1939. *Polish text; French abstracts.*

Le Silurien de Volhynie d'après le Sondage de Bocianowka. ZBIGNIEW SUJKOWSKI. Pp. 29; figs. 2; pls. 4. Inst. Géol. de Pologne, Bull. 12, Warsaw, 1939. *French text.*

Petrographische Untersuchungen in Nordost-Polen. MARIAN MALKOWSKI AND OTHERS. Pp. 24; fig. Inst. Géol. de Pologne, Bull. 13, Warsaw, 1939. *Polish text, German abstracts.*

Petrographische Untersuchungen in Volhynien. J. WOJCIECHOWSKI AND OTHERS. Pp. 30; figs. 2; pl. Inst. Géol. de Pologne, Bull. 14, Warsaw, 1939. *Polish text, German abstracts.*

Estado Actual da Paleobotanica Brasileira. EUZEBIO DE OLIVEIRA. No. 10, pp. 16; No. 11, pp. 14; fig. Serviço Geol. e. Min. Notas Preliminares e Estudos Nos. 10 and 11, Rio de Janeiro, 1939.

Um Estudo Sobre a Gypsita. GERSON DE FARIA ALVIM. Pp. 16. Serviço Geol. e. Min. No. 12, Rio de Janeiro, 1937.

O Valle do Amazonas. MATHIAS G. DE OLIVEIRA ROXO. Pp. 16. Serviço Geol. e. Min. No. 17, Rio de Janeiro, 1938.

Relatorio Annual do Director. EUZEBIO DE OLIVEIRA. 1935, pp. 187; 1936, pp. 148. Serviço Geol. e. Min., Rio de Janeiro.

Noções Summarias de Palaeophytologia. MATHIAS G. DE OLIVEIRA ROXO. Pp. 23; figs. 22. Serviço Geol. e. Min. Bol. 76, Rio de Janeiro, 1938.

A Politica do Ouro. EUZEBIO P. DE OLIVEIRA. Pp. 46. Serviço Geol. e. Min., Bol. 73, Rio de Janeiro, 1937.

Introduccao ao Estudo dos Reptis Fosseis do Brasil. MATHIAS G. DE OLIVEIRA ROXO. Pp. 76; figs. 69; pls. 2. Serviço Geol. e. Min. Bol. 89, Rio de Janeiro, 1937.

Regionale Geologie der Erde. Bd. 3. Jüngere Orogenetische Zonen. Abs. IVa. The North American Cordillera and the Caribbean Region. A. C. WATERS AND H. D. HEDBERG. Pp. 60; Figs. 9; Pl. 1. **Abs. IVb. Die Kordilleran von Südamerika.** H. GERTH. Pp. 72; Figs. 12; Pl. 1. Akademie Verlagsgesellschaft. M.B.H. Leipzig, 1939. Price, 17 RM. *A concise statement and discussion of the tectonic and magmatic events from which may be derived the geological development and present structure of the Cordilleran regions of the Americas.*

Mineral Industry, Vol. 47, 1938. G. A. ROUSH, ed. Pp. 784. McGraw-Hill Book Co., New York, 1939. Price, $12.00. *The customary statistics of commercial minerals brought up to date.*

Contributions to the Paleobotany of Middle and South America. E. W. BERRY. Pp. 168; pls. 23; figs. 3. Johns Hopkins University, Studies in Geology, No. 13. Baltimore, 1939. Price $2.00. *Five papers.*

Schneestudien im Oberwallis und ihre Anwendung auf den Lawinenverbau. E. EUGSTER. Pp. 84; pls. 7; figs. 42. Beit. z. Geol. der Schweiz, Geotech. Ser., Hydrologie, Lief. 2. Bern, 1938.

Der Schnee und seine Metamorphose. H. BADER, R. HAEFELI, E. BUCHER, J. NEHER, O. ECKEL, CHR. THAMS, AND P. NIGGLI. Pp. 340; figs. 151; pls. 18; tables 8. Beit. z. Geol. der Schweiz, Geotech. Ser. Hydrologie, Lief. 3. Bern, 1939. *Two amazingly comprehensive and detailed volumes on many features of snow that few geologists have dreamed of; including microscopic petrography, porosity, mechanics, and a wealth of other data; beautifully printed and illustrated.*

A Unique Clay from the Goose Lake, Illinois, Area. R. E. GRIM AND W. F. BRADLEY. Pp. 19; figs. 4; tables 8. Illinois Geol. Surv., Rep't of Invest.—No. 53. Urbana, 1939. *A nonbentonitic clay possessed of many useful properties, marketed under the name "Grundite."*

Oil and Gas Developments in Illinois in 1938. A. H. BELL. Pp. 28; figs. 2; tables 7. Illinois Geol. Surv., Illinois Petroleum, No. 33. Urbana, 1939. *Statistical.*

Recent Developments in Illinois with Discussion of Producing Formations Below McClosky "Sand." A. H. BELL AND G. V. COHEE. Pp. 15; figs. 3; tables 2. Illinois Geol. Surv., Illinois Petroleum, No. 34. Urbana, 1939.

Geology and Mineral Deposits of the Omaruru Area, South West Africa. S. H. HAUGHTON, H. F. FROMMURZE, T. W. GEVERS, C. M. SCHWELLNUS, AND P. J. ROSSOUW. Pp. 160; pls. 13; figs. 33. S. Africa Geol. Surv., An Explanation of Sheet No. 71 (Omaruru, S.W.A.). Pretoria, 1939. Price 5s with map, scale 1 in. to 1.97 miles, 20″ × 38″, in color. *Damara System limestones intruded by a progressive differentiation series of granitic rocks, giving rise to pegmatite, tin, tungsten, and other deposits.*

Annual Report 1939, Tanganyika Geol. Surv. F. B. WADE. Pp. 27. Dar es Salaam, 1939. Price Sh. 1/50. *Administrative.*

Explanation of the Geology of Degree Sheet No. 18 (Shinyanga). G. J. WILLIAMS AND N. W. EADES. Pp. 23; maps 2. Tanganyika Geol. Surv., Bull. 13. Dar es Salaam, 1939. Price Shs. 2/50 including geological map, 20″ × 23″, scale 1:250,000, in color. *Diamonds in kimberlite; gold prospects.*

Report on a Short Visit to Marudi Mountain Gold Workings, Rupununi District, British Guiana, in 1934. D. R. GRANTHAM. Pp. 5; sketch map. British Guiana Geol. Surv., Bull. 13. Georgetown, 1939. Price 12 cents.

Winston County Mineral Resources. F. F. MELLEN AND T. E. MCCUTCHEON. Pp. 169; pl. 1; figs. 32. Mississippi Geol. Surv., Bull. 38. University, 1939. *Ceramic clays.*

Geology and Water Resources of the Mud Lake Region, Idaho. H. T. STEARNS, L. L. BRYAN, AND L. CRANDALL. Pp. 125; pls. 12; figs. 9. U. S. Geol. Surv., W. S. P. 818. Washington, 1939. Price 75 cents, *including geological map, 32″ × 42″, scale probably 1: 125,000, in color.*

Iron and Steel Industries of Europe. C. W. WRIGHT. Pp. 98; map. U. S. Bur. of Mines, Econ. Paper 19. Washington, 1939. Price 20 cents. *A brief but comprehensive report on the resources, production, consumption, reserves, and many other related features; by countries.*

Mining and Milling Methods and Costs at the Black Hills Tin Co., Tinton, S. Dak. J. R. GUITERAS. Pp. 16; figs. 2; tables 13. U. S. Bur. of Mines, Info. Circ. 7084. Washington, 1939.

Lachute Map-area. Part I, General and Economic Geology. F. FITZ OSBORNE. Part II, The Lowlands Area. H. W. MCGERRIGLE. Part III, Magnesitic-Dolomite Deposits, Grenville Township. F. FITZ OSBORNE. Pp. 91; pls. 10; figs. 2; maps 5. Quebec Bur. of Mines, Ann. Rpt. 1936, Part C. Quebec, 1938. *With two geological maps in color, each 26″ × 39″, scale 1″ to 1 mile. Covers about 1300 square miles of the important region between Ottawa and Montreal.*

Geology and Mineral Deposits of Bridge River Mining Camp, British Columbia. C. E. CAIRNES. Pp. 140; pls. 6; figs. 5; maps 2. Canada Geol. Surv., Mem. 213. Ottawa, 1937. Price 50 cents. *Geological maps in color of Gun Lake Area, 24″ × 36″, and Cadwallader Creek Area, 26″ × 32″, both at 1:31,680 scale, and detail map of the area including the Bralorne and Pioneer Mines, 13″ × 22″, at 1:9,600 scale.*

Stratigraphy and Structure of Turner Valley, Alberta. G. S. HUME. Pp. 19; maps 3; sections 6. Canada Geol. Surv., Paper 39–4. Ottawa, 1939. *Explanation of the maps: A (structure) and B (geology) of N. half, 48″ × 28″, and C (geology) of S. half, 38″ × 56″; all at 4″ to 1 mile scale. Advance copies (white prints); excellent.*

Report of Mines and Geology Branch for the Fiscal Year Ending March 31, 1938. J. MCLEISH. Pp. 59. Ottawa, 1939. *Administration statistics.*

Opawica Lake and Lewis Lake Map-Areas, Abitibi Territory, Quebec. G. SHAW. Pp. 7; maps 2. Canada Geol. Surv., Paper 39–2. Ottawa, 1939. *Explanation of the two maps, E. half and W. half, each 30″ × 40″, scale probably 2″ to 1 mile. Advance copies (white prints).*

Geological Map of the Front Range Mineral Belt, Colorado (Explanatory Text). T. S. LOVERING AND E. N. GODDARD. Pp. 48; pl. 1; figs. 4. Colorado Sci. Soc. Proc., vol. 14, Pt. 1. Denver, 1938. *Structural influence on ore deposition; format, type, and paper exceptionally good.*

Preliminary Geological Report on the West Slope of the Mosquito Range in the Vicinity of Leadville, Colorado. C. H. BEHRE, JR. Pp. 30; figs. 3. Colorado Sci. Soc. Proc., vol. 14, Pt. 2. Denver, 1939. *Type and paper changed.*

Maryland State Geological Map. Maryland Geol. Surv. Baltimore, 1939. *Two sheets, each 26″ × 42″, scale 1″ to 6 miles, in color.*

Geological Maps, Frederick Co., and Carroll Co., Maryland. Maryland Geol. Surv. Baltimore, 1939. *Each 36″ × 50″, scale 1:62,500, in color.*

SOCIETY OF ECONOMIC GEOLOGISTS

The Nineteenth Annual Meeting of the Society will be held with the Geological Society of America, Dec. 28–29, 1939, at the Hotel Nicollet, Minneapolis, Minn.

The Society will participate in the functions of the Geological Society of America.

The Program Committee have arranged the following program:

Thur. 9 A.M. Scientific sessions of the G. S. A.

Thur. 2 P.M. Papers by G. C. Branner, S. W. Lohman and J. C. Frye, S. L. Schoff, T. W. Robinson, M. K. Hubbert, F. B. Plummer and H. K. Livingston, G. H. Cady and C. C. Boley (see abstracts, pages 939–948).

Thur. 8 P.M. Address of the retiring President of the Geological Society of America, T. Wayland Vaughan, followed by the annual smoker of the G. S. A.

Fri. 9:15 A.M. Papers by C. H. White, T. M. Broderick, E. S. Moore, T. S. Lovering, A. H. Koschmann, C. F. Park, T. G. Andrews, C. Tolman and C. Meyer, W. J. Miller (see abstracts, pages 939–948).

Fri. 11:35 A.M. Joint session with the G. S. A. Address of the retiring President of the Society of Economic Geologists, E. S. Moore: Genetic Relations of Gold Deposits and Igneous Rocks in the Canadian Shield.

Fri. 12 M. Luncheon of the Society.

Fri. 2 P.M. Joint session with the Geological and Mineralogical Societies of America. Papers by F. L. Cuthbert; E. B. Mathews; C. H. Behre, Jr.; E. F. Osborn and J. F. Schairer; P. F. Kerr; C. Goodman, K. G. Bell and W. L. Whitehead; R. M. Dreyer; S. S. Philbrick; E. B. Sandell and S. S. Goldrich; C. N. Apsouri (see G. S. A., M. S. A. and S. E. G. abstracts).

Fri. 8 P.M. Annual dinner of the G. S. A.

SOCIETY OF ECONOMIC GEOLOGISTS

Abstracts of papers to be presented at the Twentieth Annual Meeting in conjunction with the Geological Society of America, Minneapolis, Minnesota, Dec. 28–30, 1939.

*THE GENESIS OF THE FERBERITE AND GOLD TELLURIDE ORES OF BOULDER COUNTY, COLORADO.**

T. S. LOVERING.

The wall rock alteration adjacent to the tungsten veins shows a narrow sericitized casing surrounding the vein, giving away abruptly to an argillized envelope extending to as much as fifty feet from the vein. The argillitic alteration indicates attack by early acid solutions and the narrow sericitized sheath shows a change to neutral and alkaline solutions at a late stage. In the gold telluride veins the sericitic alteration is dominant and the argillitic envelope is generally lacking. The early vein quartz shows that the clay minerals and marcasite immediately preceded the deposition of contemporaneous pyrite and ferberite. Hypogene brown iron oxide is later than the ferberite and is followed by barite and adularia. This mineralogy indicates a progressive change from acid to alkaline solutions and harmonizes with the evidence of wall rock alteration. Ferberite was apparently precipitated in slightly acid solutions, but galena, tetrahedrite, chalcopyrite, sphalerite, and miargerite are later and were presumably precipitated in alkaline solutions. Gold telluride is still later in the normal sequence and also is believed precipitated in alkaline solutions. Field evidence suggests that the source rock was a biotite latite heavily charged with volatiles and represented by dikes of latite and latitic explosion breccia. It is suggested that emanations from the underlying magma rose through the hot porous explosion breccia with little change in character, but soon dropped their load above the upward termination of the breccia in the overlying fissures where they reacted with the wall rock and became neutralized and finally alkaline through the acquisition of bases from the quartz monzonite that makes up the country rock of the deposit.

GEOLOGY OF THE ROPES GOLD MINE, MARQUETTE COUNTY, MICHIGAN.

T. M. BRODERICK.

The Ropes Mine, situated three miles northwest of Ishpeming, Michigan, was operated from 1883 until 1897 and produced $647,902 gold and silver.

The ore mined occurred in nearly vertical quartz lenses cutting diagonally across a vertical tabular body of Keewatin lavas and volcanic fragmentals separating two bodies of peridotite. The Keewatin and immediately ad-

* Indicates that abstract is published by permission of the Director, *Geological Survey*, U. S. Department of the Interior.

jacent peridotite are strongly sheared, the former being chloritized and the latter serpentinized and steatitized. In the vicinity of the quartz lenses the Keewatin is silicified, sericitized and carbonatized. The mineralization is probably of post middle Huronian age.

The quartz veins carry tetrahedrite, pyrite, chalcopyrite, and minor amounts of other sulphides, and the ore milled ran about .2 oz. gold and .9 oz. silver per ton, of which nearly one-third was lost in the tailings.

Recent explorations have shown another type of ore occurring as a pyritic dissemination in schist adjacent to the quartz veins. There is about eight times as much ore of this type averaging .13 oz. gold and .6 oz. silver as there was in the quartz vein nuclei.

The old mine was over 800 feet deep and recent diamond drilling from the bottom level has shown the persistence of favorable rock alteration and gold values for hundreds of feet below that elevation.

*GROUND-WATER CONDITIONS OF THE DAKOTA SANDSTONE IN NORTHWESTERN IOWA.**

THOMAS W. ROBINSON.

The ground water of the Dakota sandstone in northwestern Iowa occurs under artesian conditions, but nowhere, so far as is known, is the head sufficient to produce natural flow of water from wells at the land surface. The general hydraulic gradient and direction of movement of the ground water in this area is shown by a contour map of the piezometric surface. In general the movement of water is from north to south. A prominent feature of the piezometric surface is a broad ground-water ridge or divide that begins about 60 miles east of the South Dakota State line and extends southward approximately 100 miles from the Minnesota State line. East of this divide, movement of the water is toward the southeast and west of it the movement is toward the southwest. Locally in the heavily pumped areas there has been some decline in the artesian head.

USE OF THE INTERNATIONAL BUSINESS MACHINE METHODS IN RECORDING COAL DATA.†

GILBERT H. CADY AND CHARLES C. BOLEY.

The Coal Division of the Illinois State Geological Survey employs International Business Machine methods for recording and tabulating datum points used in the construction of structure contour maps. On a punch-card there are shown critical data with respect to the location and nature of the datum points, the surface altitude, and the depth, thickness, and altitude of the key coal beds. By using the punch-card method data can be assembled quickly for distribution to accompany structure maps at a relatively small cost compared with stenographic preparation.

A second punch-card system has also been developed for the recording and tabulation of a great variety of chemical data, such as source of sample, the items of the proximate and ultimate analyses on various bases, the items of the ash analysis, BTU values on various bases, and considerable incidental information of significance in the Survey records. The punch-card system permits the mechanical handling and sorting of data with respect to a variety of criteria and greatly facilitates statistical study of chemical data and the tabulation of information.

† Published by permission of the Director, Illinois Geological Survey.

THE RADIOACTIVITY OF SEDIMENTARY ROCKS AND ASSOCIATED PETROLEUM.

CLARK GOODMAN, K. G. BELL, AND W. L. WHITEHEAD.

Determinations of the radioactivity of 21 sedimentary rocks and 7 associated crude oils have been made by the precision method developed by R. D. Evans. The specimens consisted of cuttings and cores from wells in the Bartlesville, Cromwell, Frio, Woodbine and Viola-Simpson formations. Considerable variability in radioactivity was found in the sandstones (1.4 to 0.19×10^{-12} gms. Ra/gm) and limestones (1.3 to 0.18×10^{-12} gms Ra/gm). The radium content of limestones decreases with increasing purity. The shales were quite uniform (1.2 to 1.0×10^{-12} gms Ra/gm). Apparently, discrete mineral particles in sandstone and impurities in limestone account for their occasional high radioactivity. The radon content of the crude oils (0.47 to 0.05×10^{-12} curies/ gm of oil) was in one sample 38 times, and averaged 10 times, the amount in equilibrium with the radium present. The results corroborate the inferences of former investigators that radon tends to concentrate in crude oils. Maximum radon content and maximum ratio of radon to radium were found in petroleum produced from a permeable, Oligocene (Frio) sandstone of high radioactivity. Cracking of hydrocarbons with generation of hydrogen has been proved by S. C. Lind to result from bombardment with alpha rays. The amounts of radioactivity found in these crude oils are quantitatively sufficient to cause appreciable cracking by alpha radiation during geologic time. These reactions, together with subsequent hydrogenation, may account for important changes in petroleum. This hypothesis would also explain the presence of hydrogen in some natural gases. The hydrogen content of oil gases is suggested as a possible method of geophysical prospecting for oil fields.

STATE MINERAL SURVEY IN ARKANSAS.

GEORGE C. BRANNER.

A State Mineral Survey Project was initiated on January 7, 1938, in Arkansas by the Works Progress Administration, under the sponsorship of the Arkansas Geological Survey, and will continue for at least six months from October 31, 1939.

A study is being made of the easily identifiable and accessible minerals, together with ground and surface waters. A laboratory has been constructed to undertake mineral and water analyses, and a furnace has been constructed for burning clays.

Approximately 22,300 square miles have been surveyed, at a total cost to all participants of $579,642.88, to October 31, 1939. This is an average cost of $26.14 per square mile.

A maximum of 663 persons has been simultaneously employed on the project, and 1,140,182 man hours have been expended to October 31, 1939. This is an average of 51.1 man hours per square mile.

A great amount of valuable data has been collected and is being organized for publication. The conclusion has been reached that untrained personnel can be successfully utilized to gather data on mineral resources and collect samples, provided the individual tasks are reduced to relatively simple and routine procedures and the supervision is reasonably adequate.

GROUND WATER IN THE OKLAHOMA PANHANDLE.*

STUART L. SCHOFF.

The Oklahoma Panhandle, an area of about 5700 square miles, is part of the Southern High Plains. An investigation begun in 1937 by the Geological Survey, United States Department of the Interior, and the Oklahoma Geological Survey, has shown that the depth to the water table in the area ranges from less than 25 feet in parts of major valleys to about 300 feet in parts of the uplands. In 8 areas of upland plains the depth to the water table is between 50 and 100 feet. The thickness of the zone of saturation differs widely in these areas, the most promising of which totals about 80 square miles in northeastern Texas County. The pervious sands and gravels of the Ogallala formation, of Pliocene age, furnish most of the ground water, and one well yielding 960 gallons a minute from them has been used for irrigation since 1937. The formation ranges from less than 100 to more than 500 feet thick, the differences being due to relief on the pre-Ogallala topography and to post-Ogallala erosion. The alluvium is also an important source of water, as are the Dakota and Cheyenne sandstones, of Cretaceous age. A few wells obtain water of variable quality from Jurassic and Triassic rocks, and many wells in the valleys of the eastern part of the area obtain small supplies of highly mineralized water from Permian red beds.

CAPILLARY PHENOMENA IN OIL RESERVOIRS.

F. B. PLUMMER AND H. K. LIVINGSTON.

Types of natural fluid reservoirs are briefly illustrated and the importance of a better understanding of water oil relationships in fine-grained sand reservoirs is emphasized. A new experimental apparatus for studying reservoir conditions and radial flow of fluids through sands under more natural conditions is demonstrated. Various ways of reducing the percentage of water and increasing the percentage of oil flowing through a sand in reservoirs containing both water and oil are illustrated and discussed in some detail.

GEOLOGY IN A LITIGATION CASE.

E. S. MOORE.

A case is described in which the geological evidence was so definite that conclusions could be drawn regarding the age of an ore deposit, its relations to faulting, and the future possibilities of the property on which it was located. The geological setting and evidence employed are described in detail.

GEOLOGY AND GROUND-WATER RESOURCES OF THE "EQUUS BEDS" AREA IN SOUTH-CENTRAL KANSAS.*

STANLEY W. LOHMAN AND JOHN C. FRYE.

The so-called Equus beds area embraces those parts of McPherson, Harvey, Reno, and Sedgwich Counties underlain by beds formerly classi-

fied as the McPherson formation, but commonly called the "Equus beds." Interest in these deposits as sources of ground water led, in July, 1937, to a detailed investigation by the United States Geological Survey in cooperation with the Kansas Geological Survey and the Kansas State Board of Health. The scope of the investigation was enlarged considerably during 1938 and 1939 by the additional cooperation of the City of Wichita in an effort to develop a more suitable ground-water supply. As a result of this investigation a new supply has been found and tested about 25 miles northwest of Wichita.

The deposits formerly referred to the McPherson formation of Pleistocene age were remapped and more properly classified to include: (1), the Emma Creek formation, consisting of sands, gravels, clays, and silts of Middle and Upper Pliocene age; (2), the McPherson formation redefined, comprising outwash sands and gravels and locally derived sands, silts, and clays, of Pleistocene age; (3), a thick Pleistocene loess; (4), Pleistocene and Recent dune sands; and (5), Recent Alluvium.

The principal hydrologic studies included: (1), the sinking of about 100 drilled test wells; (2), the driving of about 60 wells for determining water levels and the movement of oil-field brines; (3), the collection of numerous water samples for chemical analysis; (4), the construction of a detailed water-table contour map; and (5), water level measurements in several hundred wells to determine extent of recharge.

THE PEGMATITES OF THE KEYSTONE AREA.

CONSTANTIN N. APSOURI.

Detailed mapping of the Hugo, Peerless, Dan Patch, Bob Ingersoll and lesser pegmatites in the Keystone area, supported by critical study of the relations between their minerals and the country rock lead the writer to conclude that:

(1) Some criteria interpreted as favoring replacement need revision, having been used to support two diametrically opposed views; examples are euhedral crystals.

(2) Even a well-established criterion should be employed in the light of spatial and structural relations.

(3) While replacement did take place, its role is over-emphasized. The spodumene "logs" at the Etta mine are not products of replacement.

(4) The common belief that muscovite and muscovite books are replacement products is not supported by the field evidence cited by advocates of replacement. Muscovite forms less than 1% in common pegmatites. The contention that mica occurs at the contact is not strictly correct; mica books are generally far from a major contact. Not all pegmatites bear mica. The almost constant association of schist xenoliths with an aureole of muscovite books suggests a genetic relationship. The mica probably resulted from the assimilation of the schist by the pegmatitic magma.

(5) Structure and mode of emplacement of pegmatites has not been stressed lately. Pegmatites distend the country rock, or stope their way through, or both, as suggested by xenoliths and the sharp transgression of schistosity by some contacts.

(6) The sequence of mineral paragenesis described by Landes (1928) is revised.

(7) A single mapping of a pegmatite is insufficient. Repeated visits and mapping, concurrent with the progress of mining, are essential to uncover significant data, otherwise irretrievably lost.

STRUCTURAL CONTROL IN EUROPEAN LEAD-ZINC ORES OF THE MISSISSIPPI VALLEY TYPE.

CHARLES H. BEHRE, JR.

This discussion is limited to tectonic, non-mineralogic features, observed during nine months of field work, supplemented with observations by others.

The flat-lying strata of German and Polish Silesia and those of the north Moroccan deposits (Oujda, Touissit) show ore following bedding-partings near normal faults; absence of obvious trunk channels suggests the Upper Mississippi Valley and Tri-State relationships in the United States. The ores near Alston (northern England) and Djalta (Tunisia) are similar. Somewhat similar also are those of Derbyshire (Mill Close mine) but here mineralized fissures are well exposed.

At Aachen and near-by Limburg (Holland) and Moresnet (Belgium) mineralized large faults, from which the ore spread outward, are well-marked and bedding plane openings are still prominent. But in Wales (Halkyn) and the middle Rhine valley (e.g., Ems) fault openings play the only important role.

At the opposite extreme from the Silesian deposits are replacements and fissure fillings in Alpine limestones at Mezica (Jugoslavia), Cave di Predil (Italy), and Bleiberg (Austria). These show replacements confined to the neighborhood of complex faults, largely thrusts, yet mineralogy and paragenesis are essentially as in the cases first cited.

Summarizing, widespread studies yield transition types between (1) deposits in highly strained rocks and (2) deposits in almost undeformed sediments, in which the direction of mineralization is still actively debated, both here and abroad. The tectonic relations of the less deformed types can therefore scarcely be adduced as arguments against hydrothermal origin.

*MANGANESE DEPOSITS IN THE OLYMPIC PENINSULA, WASH.**

CHARLES F. PARK, JR.

The Olympic Peninsula, Wash., is bordered on the northern, eastern, and southern parts by a thick sequence (30,000 feet) of volcanic rocks, argillites, graywackes, and limestones of lower Eocene age. These rocks are much deformed, and dips of less than 45° are uncommon. The less competent strata, particularly the limestones and limy argillites, are much contorted, both as a result of the mountain building processes and of the pouring out of lava on the limy muds of the sea bottom. Chocolate-red limestone that contains as much as 10 percent of finely divided hematite is of especial interest, as it forms the common host rock for the manganese. The limestones are associated with lavas, particularly pillow basalts. They underlie and overlie the lava, form the matrix between

pillows or agglomerate fragments, and in some places form beds at the edges of lava flows.

The manganese is of low-temperature, hydrothermal origin and occurs in irregular lenses and bodies that have replaced red limestone or red limy argillite. In a few places the manganese minerals have replaced lava, as indicated by remnants of pillow structures. The manganiferous bodies are generally small and contain from a few to a few hundred tons of ore, but some bodies are considerably larger. At the Crescent mine about 25,000 tons of high-grade hausmannite (Mn_3O_4) have been mined. Exploration, however, has been, for the most part, superficial and insufficient to determine the limits of the ore bodies.

The mineral composition of the ores is unique, in that the ore consists of hausmannite and a fine-grained mixture of manganese silicates commonly called "bementite." Small quantities of cinnabar and native copper are widely distributed throughout the deposits. The hausmannite deposits, notably of the Crescent mine, are low in silica. Other deposits contain small amounts of oxides and are chiefly manganese silicates. Still other bodies contain only manganese silicates and jasper and grade into bodies of bright red jasper that may or may not contain small amounts of manganese silicates.

A GALENA-SPHALERITE DEPOSIT IN NORTHEAST ALABAMA.

T. G. ANDREWS.

Near Angel Station, Calhoun County, Alabama, galena and sphalerite occur in Ordovician limestone. The deposit has been known since before 1860, and sporadic attempts have been made to develop the property. A small quantity of lead was produced during the War Between the States.

The minerals occur in small veinlets and as disseminations in fractured limestone. The deposit is adjacent to a fault. Later movements have caused crushing and granulation of the minerals with destruction of the cubic cleavage of the galena. The deposits are thought to be hydrothermal in origin.

CUNEIFORM FRAGMENTS DIAGNOSTIC OF FAULT BRECCIA.

CHARLES HENRY WHITE.

In tectonics and especially in the search for ore it is important to distinguish fault breccia from detrital breccia. Where exposures do not reveal the form or geologic relations of the deposit, the fragments themselves may provide the only clues to their origin.

Trituration in a fault zone produces cuneiforms with convex faces which meet in wedge-like edges in sharp contrast with rounded edges and irregular or concave faces of water-worn fragments.

THERMODYNAMICAL APPROACH TO THE FLOW OF GROUND WATER.

M. KING HUBBERT.

Much unnecessary confusion prevails regarding the physics of the flow of ground water. Darcy's law, the foundation of ground water flow and its related parameter, permeability, are currently employed under several different working definitions based upon widely different fundamental conceptions. Among these are: the erroneous conception that "water flows from regions of higher to those of lower pressure," the conception of limited validity that the flow is determined by the configuration of the piezometric surface, and that based upon a false analogy with the assumed frictionless fluids of classical hydrodynamics that ground water flow is derivable from a velocity potential.

Physical validity is achieved and confusion eliminated by a thermodynamical approach wherein it is recognized that the flow of ground water is essentially an irreversible transformation involving the creation of thermal energy at the expense of mechanical energy and always occurs in such a direction as to diminish the mechanical energy of the system, zero flow corresponding to a state of minimum mechanical energy.

Upon this basis the hydraulic potential at any point in the system may be defined to be the mechanical energy required to inject unit mass of the liquid into the system at that point from some arbitrary standard state. This leads to the fundamental equation of flow:

$$q = -\sigma \frac{\partial \Phi}{\partial n}$$

where q is the flow vector, σ a conductivity parameter for the liquid and medium, and $\partial\Phi/\partial n$ the gradient of the hydraulic potential. This is an expression of Darcy's law, and is physically as well as mathematically analogous to Ohm's law in electricity and leads to all the same familiar deductions.

PRE-CAMBRIAN IRON MINERALIZATION IN SOUTHEAST MISSOURI.**

CARL TOLMAN AND CHARLES MEYER.

The emplacement of the iron deposits in the pre-Cambrian felsites of southeast Missouri was initiated by an early hematite stage which is best developed in the fissure fillings near the crest of Shepherd mountain, Missouri.

Subsequently the iron-depositing solutions became reducing in chemical character, and partial conversion of the hematite to pseudomorphic magnetite was effected. Much primary magnetite, accompanied by minor amounts of sulphide, was also deposited during this second stage, both as tiny veinlets penetrating older hematite lathes and as extensive fissure fillings and replacements such as those on Iron Mountain.

Late hydrothermal oxidation probably accomplished most of the observed martitization of the magnetite, since this reaction seems to have been induced by solutions still capable of depositing late platy hematite.

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Martitization along the octrahedral planes predominates at Iron Mountain, as evidenced by the lattice arrangement of hematite crystals which may be observed even though little magnetite now remains and no external crystal form may be present. Selective oxidation of concentric zones in magnetite crystals were also noted, as well as the common more irregular ingressions of hematite on magnetite without reference to crystallographic orientations or original crystal growth.

ORIGIN OF THE MAGNETIC IRON ORES IN THE LYON MOUNTAIN REGION, NEW YORK.

WILLIAM J. MILLER.

Various theories, including one by the writer, have been set forth to explain these magnetite deposits. After a brief review of theories, particular attention is given to the most recent one, advocated by Gallagher in 1937.

Main points for discussion include: cutting to pieces and penetration of an old gabbro and metagabbro by the pegmatite-rich Lyon Mountain granite; the abundance of mineralizers in the granite magma as a great aid in its intimate penetration and transformation of the old iron-rich gabbro, accompanied by the setting free of much magnetite to form the principle source of the iron ores; Gallagher's claim that there was not enough iron-rich gabbro to supply the ore; the origin of the so-called gray bands; and the role of pneumatolytic metasomatism during the process of ore deposition.

*THE GEOLOGY AND VEIN SYSTEMS OF THE CRIPPLE CREEK DISTRICT, COLORADO.**

A. H. KOSCHMANN.

The Cripple Creek district consists essentially of an irregular mass of breccia about 4×2 miles in area occupying a steep-walled basin in pre-Cambrian rocks. Recent work has revealed that the breccia contains much non-volcanic waterlaid material. New fossil, structural, and petrologic evidence favors the conclusion that the main mass of fragmental material occupies a basin formed by subsidence but obscured by contemporaneous and subsequent igneous activity, rather than by the formation of an immense explosion crater.

Well-bedded, waterlaid strata have a wide horizontal and vertical distribution. They are best seen in the eastern part of the basin, where at least 700 feet of interbedded conglomerate, arkose, shale, and limestone, derived from the pre-Cambrian rocks, are found. They are unconformably overlain by volcanic rocks 450 feet thick. Bedding is in part parallel to the underlying granite surface and dips as much as 40°.

Elsewhere in the district well-bedded conglomerate and tuff are found locally as much as 2,000 feet and well-sorted material 3,000 feet below the surface. Bedding in places is nearly horizontal but elsewhere has been tilted by igneous action or, more probably, by local faulting. The restriction of coarse granitic debris in the volcanic breccia close to the margins of the basin implies derivation from steep slopes or cliffs. In places granitic and volcanic material are mixed in undoubted fault gouge

and show that subsidence by faulting continued after much volcanic material has been erupted.

The volcanic material was evidently erupted from local fissures and vents but none have been recognized as actual sources of the volcanic breccia. The best defined eruptive center is the Cresson "blowout," the latest of the volcanic rocks. Older centers are roughly indicated by local masses of coarse breccia and by chimney-like intrusive masses that may have eliminated early breccia pipes.

Regional structure indicates that configuration of the breccia area has been controlled by pre-existing old fractures, along which subsidence of the breccia mass took place and along which igneous processes were active. During subsidence the floor of the basin was broken into fault blocks some of which subsided to great depths. Four buried granite ridges trending northwest and essentially parallel with the major axis of the basin have been exposed underground. Their steep slopes and relationship to the basin indicate that they are horsts.

Dikes and vein zones coincide with or parallel the dominant trends of the contact between granite and breccia. They indicate periodic disturbances along old fissures throughout the later stages of volcanic and hydrothermal activity.

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